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Innovating Disaster Risk Reduction (DRR) Framework for Ensuring Urban Resilience: A Study on Coastal Delta Cities

Md. Sarfaraz Gani Adnan*

Abstract

Coastal delta cities are at risk to hydro meteorological hazards especially from flooding. To reduce this risk many cities have built extensive flood defence system that can only reduce the probability of flood occurrence. So, the study is focusing on developing a framework for selecting the most suitable flood risk reduction policies according to the local situation which will ensure resilience. First, from the physical and environmental point of view 10 DRR policies have been identified under three broad approaches based on the DRR initiatives by eleven precedent (model) cities. After that few explanatory variables are selected on the basis of geography, climate, flood hazard, risk magnitude and economic aspects. Then a correlation has been established among DRR policies and explanatory variables and then the pattern of correlations have been explained. The findings of this study show a framework from where appropriate DRR policies can be selected. It has been observed that in a stable political situation, a city can decide to adopt various DRR policies based on geography and climate, hazard pattern, magnitude and experience. The study further reveals that along with structural flood protection, practicing environmental and planning management can reduce the flood risk in coastal cities.

Introduction

Coastal delta cities are at risk to natural hazards, particularly to flooding. And flood exposure in those coastal regions has been increasing, owing to growing population, climate change, and subsidence (Hallegatte, et al., 2013). Additionally, the lower elevation of these deltaic regions makes the flood situation even worse. Furthermore, sea level rise and the possibility of more intense storms are of particular concern which usually exacerbates flood situation (Nicholls, et al., 2008).. This incorporates every aspect of human life, every physical phenomenon, economic environment, natural world and so on. The main challenge of reducing risk from natural hazards is "to find a way to live with these phenomena, rather than die from them" (UNISDR, 2004). Moreover, cities are dynamic in nature and spatial distribution of population cannot be the same over the years. On the contrary, cities which are not in an ideal condition to invest large sum of money to build expensive flood defences, are often struggle to find an optimum way to reduce this risk. Consequently coastal delta region remains flood prone where trillions of dollars' worth of asset are located (Alerts, et al., 2014). By recognizing this risk of flooding this study is aiming at developing a framework for selecting the most suitable flood risk reduction policies according to the local situation which will ensure resilience.

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* Assistant Professor, Department of Urban and Regional Planning, Chittagong University of Engineering and Technology (CUET), Chittagong, Email: sarfaraz_adnan@yahoo.com

Theoretical Framework

In the field of disaster management generally resilience means the capacity of a system to withstand in a certain hazard and also the ability to bounce back after that extreme event (Coles & Buckle, 2004; Godschalk, 2003; Gordon, 1978; Klein, et al., 2003; Twigg, 2007; Zhou, et al., 2010). On a broader picture to ensure resilience, five broad aspects need to be taken into account e.g. environmental, physical, social, economic and institutional (Cutter, et al., 2008; Shaw & IEDM Team, 2009; Zhou, et al., 2010). However, various studies as well as international documents have proposed different policies to reduce the flood risk. As for instance, Klein et al. (2003) has suggested that changing the land use and location of development can help to avoid hazards impact. In this regard, it is very important to assess the flood risk and delineate flood risk prone zone (Berke, 1998; Burby, et al., 1999; Hutter, 2007; UNISDR, 2004; UNISDR, 2005). Along with zoning regulation the building code, special hazard resistance building standard or even by retrofit standard for existing building stocks can strengthen existing development (Berke, 2007; Burby, et al., 2000; UNISDR, 2004).

But only planning regulation cannot protect a city from flooding as UNISDR (2004) has suggested that structural flood defence system also important. But structural measures have received some criticisms that cities in richer countries are more likely to undertake these measures (Alerts, et al., 2014; Hanson, et al., 2011; Klein, et al., 2003; Nicholls, et al., 2008). But Alerts, et al. (2014) has explained that structural flood barriers can prevent the coastal flooding but the prerequisite is that it has to be integrated with planning mechanism. Another dimension that should be given importance is the environmental aspect, because environmental degradation can exacerbates the hazard situation (UNISDR, 2004). The Hyogo Framework for Action (HFA) has mentioned that the environmental and natural resource management initiatives are the most cost effective means of DRR (UNISDR, 2004; UNISDR, 2005). But Nicholls, et al. (2008) and Hanson, et al. (2011) said that environmental policies are more feasible in developed region where the rate of urbanization is relatively low.

Public policy making process can be one of the driving forces for the selection of DRR policies. The key for public policy process is to develop a system for decision making (Bubeck, et al., 2013). In case of DRR, the major challenge is to have the right combination of policies (Birkmann & Teichman, 2010; Petak, 1985). More often lack of political commitment is observed in formulating DRR plan in comparison to humanitarian or basic development strategy which is more visible politically (UNISDR, 2004). However, by assuming a stable political situation, a development of policy process model will help the urban planners to determine the right approach for DRR. Under this circumstance David Easton's system theory can be considered as an influential concept for interpreting policy process (Bubeck, et al., 2013).

Methodology

The study has started with the selection of 11 precedent cities to elicit various policies to reduce flood risk. Delta city network (Aerts, et al., 2009) has motivated to select those precedent cities. There are a total of forty member cities and nineteen affiliated cities are within this network but among them 11 cities are selected. These 11 cities have initiated climate adaptation plan which are fully functioning within the network and these cities are acting as the frontrunner in adaptation plan.

Then various policies have been identified which are recommended to adopt for flood risk reduction. For this purpose Hyogo Framework for Action (HFA), documents from United Nations Inter-Agency Secretariat of the International Strategy for Disaster Reduction (UNISDR, 2004) and two research works Burby et al., (2000) and Hanson, et al. (2011) have been used as key references. In HFA various policies of DRR have been proposed in regards to three broad perspectives (table 2) and that is why three other documents have been used to expand the range of policies. The table 1 is summarizing the DRR policies that have been found in those four documents and furthermore highlighting the selected policies.

Table 1: DRR policies and measures that incorporated in four key documents

Document	Policies
Hyogo Framework for Action (HFA)	**Environmental and natural resource management** • Sustainable management and preserving ecosystem. • Natural resource management and encourage non structural measure of DRR. • Consideration of climate change in DRR strategy.
	Social and economic development practices • Promote food security • Protecting critical facility like health facility, infrastructure • Enhance social safety-net mechanism and post disaster recovery scheme. • Incorporation of DRR into post-disaster recovery and rehabilitation processes • Provide financial security or disaster insurance • Development Public private partnership for DRR
	Land-use planning and other technical measures • Incorporating urban planning and management in DRR • Consideration of DRR into planning procedure for major infrastructural project • Proper implementation of planning guideline and monitoring • Development based on risk assessment • Update building codes, planning standard considering risk factor
United Nations Inter-Agency Secretariat of the International Strategy for Disaster Reduction (UNISDR, 2004)	Environmental management
	Land-use planning
	Safe building construction and protection of critical facilities
	Financial and economic tools
	Early warning systems
Burby et al., 2000	Risk mapping
	Building standards

Document	Policies
	Development regulations
	Critical and public facilities policies
	Land and property acquisition
	Taxation and fiscal policies
	Information dissemination
Hanson, et al. (2011)	Upgraded protection
	Managing subsidence
	Building regulations
	Land use planning to reduce exposure, including focusing new development away from the floodplain, and preserving space for future infrastructure development
	Selective relocation away from existing city areas to reduce exposure more rapidly than is possible by only focussing on new development
	Risk sharing through insurance and reinsurance

*Shaded policies are selected for the analysis structure

Selected DRR policies are categorized under three broad approaches and a total of ten policies have been listed (Figure 1).

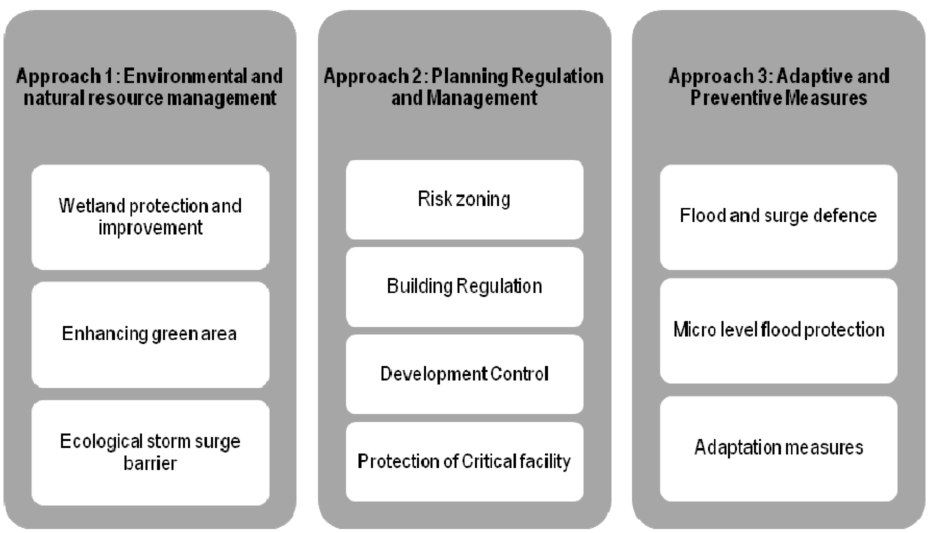

Fig. 1: Identified DRR policies under three broad approaches

Based on the identified DRR policies, next step is to draw out factors that can influence the decision in choosing these policies. In this regard, Easton's system theory has provided the theoretical basis. According to this theory public decision making is a system that is influenced by a number of factors and simultaneously can influence the environment in which it operates (Birkland, 2005). The development of simplified framework of the public policy process has been a key issue in policy science (Grin &

Loeber, 2007). It is not an easy task to predict public decision making process but some of the research works have used this theory in the field of flood risk management. Bubeck, et al. (2013) has provided a conceptual framework which explains the reason for opting different flood risk management portfolios by different countries. Based on these attributes the explanatory variables for this analysis are chosen. Since this research is limited to physical and environmental perspective, so, only relevant variables have been selected.

Table 2: Explanatory variables with description and data source

Condition and process	Variables	Description and coding	Variable ID.	Data source
Geography and climate	Delta type	1: River 2: Sea 3: River and sea	1	Dircke, et al., 2010; Yongjin, 2010
	Avg. Height (MSL)	Cities average elevation (m) from sea level	2	Dircke, et al., 2010; Yongjin, 2010
	People in low land	Number of people located in an area which is below 0.5m of sea level	3	Hallegatte, et al., 2013
	Average rainfall	Yearly average rainfall	4	Dircke, et al., 2010; Yongjin, 2010
Flood hazard	Main flood type	1: Pluvial; 2: Cyclone/Hurricane; 3: Tidal; 4: Pluvial and cyclone; 5: Pluvial and Tidal	5	Dircke, et al., 2010; Yongjin, 2010
	Sea level rise vulnerability	Projection of annual average loss due to SLR using 2050 scenario (in million US$)	6	Hallegatte, et al., 2013
	Annual average loss (AAL) ratio	Annual average loss ratio to city's GDP	7	Hallegatte, et al., 2013
Risk magnitude	Wind damage index	Wind damage index number	8	Nicholls, et al., 2008
	Current exposed population	Current number of exposed population ('000)	9	Nicholls, et al., 2008
	Percentage of current exposed population	Percentage of current exposed people in relation to total population	10	Nicholls, et al., 2008
	Current exposed asset	Current value of exposed asset (US$bill)	11	Nicholls, et al., 2008
	Current exposed asset rank	City's rank in regard to current exposed asset	12	Nicholls, et al., 2008
	Future exposed population	Number of future exposed population ('000)	13	Nicholls, et al., 2008
	Percentage of future exposed population	Percentage of future exposed people in relation to total current population	14	Nicholls, et al., 2008
	Future exposed asset	Value of future exposed asset (US$bill)	15	Nicholls, et al., 2008
	Future exposed asset rank	City rank in regard to future exposed asset	16	Nicholls, et al., 2008
Economic aspect	Per capita GDP	Country's per capita gross domestic product (US$)	17	IMF, 2014
	Damage due to hazard	Value of damaged asset due to a particular hazard	18	Dircke, et al., 2010; Yongjin, 2010

Now every explanatory variable does not have the same level of influence on various policies of DRR (figure 1). Again Bivariate correlation has been used to select highly influential variable. However, a correlation coefficient ≥ (+/-) 0.6 means highly correlated and a value between (+/-) 0.4 to (+/-) 0.6 means moderately correlated (World Press, 2014). Any correlation coefficient less than (+/-) 0.40 means poorly correlated which will not be taken into consideration for this analysis.

Analysis and Discussion

The following table is demonstrating the correlation matrix among DRR policies, measures and influencing variables related to geography, climate and flood hazard, risk magnitude and economic factors. The most significant variables are marked by shaded area along with respective correlation coefficient.

Table 3: Establishing correlation among DRR measures and explanatory variables

DRR policies and measures		Geography and climate				Flood hazard			Risk Magnitude									Economic impact	
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Environmental approach	Wetland protection and improvement	-.72	.62	-.58	-.02	.27	-.44	-.39	-.18	-.57	-.40	-.39	.35	-.48	-.44	-.37	.40	.29	-.28
	Enhancing green area	.03	.31	.18	.18	-.20	.32	.01	.31	.24	-.25	.26	.12	.37	.03	.19	-.08	.04	.06
	Ecological storm surge barrier	-.27	.46	-.66	.07	-.27	-.47	-.37	-.03	-.63	-.40	-.69	.48	-.20	-.14	-.73	.49	-.03	-.77
Planning approach	Risk zoning	.028	.194	-.18	-.244	-.20	-.56	-.39	.484	.060	-.04	.060	-.060	.120	-.07	.18	-.18	.04	-.48
	Building regulation	-.11	.00	-.39	-.43	.06	-.56	-.50	.24	-.07	-.23	-.25	-.08	-.17	-.29	-.22	.18	-.20	-.49
	Development control	-.27	.45	-.81	-.27	-.11	-.91	-.77	.22	-.51	-.52	-.60	.35	-.49	-.61	-.39	.39	.02	-.76
	Protection of critical facility	-.334	.64	-.33	.109	.20	-.22	-.58	.304	-.05	-.70	.008	.030	-.18	-.76	.237	-.11	-.145	-.16
Preventive approach	Flood and surge defence	-.17	.52	-.43	.24	-.21	-.39	-.25	-.06	-.50	-.30	-.36	.50	-.36	-.33	-.17	.22	.27	.24
	Micro level flood mitigation	-.17	.09	-.30	-.07	-.39	-.02	-.16	-.22	-.41	-.30	-.42	.71	-.22	-.30	-.46	.39	-.12	-.22
	Adaptation measures	.21	-.34	-.33	-.37	-.21	-.35	-.24	.06	.18	-.20	-.27	.21	.07	-.21	.04	.26	-.07	-.21

Highly correlated (darker shade) = coefficient ≥0.60 (5% confidence interval)

Moderately correlated (lighter shade) = 0.40 ≤coefficient<0.60

Environmental and Natural Resource Management Approach

Under the environmental and natural resource management approach three policy measures have been identified (figure 1) and it is found that nine variables (out of 18) are influencing wetland protection measure (table 3). Starting with the geography and climate, three variables are highly influential i.e. delta type, average elevation from sea level and population living in low lands. Eight out of 11 precedent cities which are located on a river and sea confluence have taken this measure (table 4). Also the land elevation is an important factor that if a particular city has relatively higher land elevation, then the place is less vulnerable to flooding.

Table 4: Precedent cities status on environmental and natural resource management approach

Explanatory Variables	Categories / range	Wetland protection and improvement		Enhancing green area		Ecological storm surge barrier	
		Adopted	Not adopted	Adopted	Not adopted	Adopted	Not adopted
Delta type	River	0	1				
	Sea	0	1				
	River and sea	8	1				
Average height from sea level (m)	0<h≤3	2	0			1	1
	3<h≤6	2	0			1	1
	6<h≤10	3	0			1	2
	h>10	1	3			0	4
Number of people living below 0.5m of sea level ('000)	≤50	1	2			0	3
	50-150	0	1			0	1
	150-300	3	0			1	2
	>300	4	0			2	2
AAL by SLR (million US$)	≤50	2	2			0	4
	51-200	2	1			1	2
	>200	4	0			2	2
Current exposed population	≤500	1	3			0	4
	500-1500	4	0			1	3
	>1500	3	0			2	1
Percentage of current exposed population	≤10	4	3			1	6
	11-20	1	0			1	0
	31-50	1	0			0	1
	≥51	2	0			1	1
Current exposed asset	≤50					0	5
	51-100					1	1
	101-150					0	1
	151-200					0	1
	>200					2	0
Current exposed asset rank	≤10					2	2
	11-20					1	2
	21-30					0	1
	31-40					0	1
	>40					0	2

Explanatory Variables	Categories / range	Wetland protection and improvement		Enhancing green area		Ecological storm surge barrier	
		Adopted	Not adopted	Adopted	Not adopted	Adopted	Not adopted
Future exposed population	≤500	1	2				
	500-1500	2	1				
	1501-2500	1	0				
	2501-5000	2	0				
	>5000	2	0				
Percentage of future exposed population	≤10	2	3				
	20-Nov	2	0				
	31-50	1	0				
	≥51	3	0				
Future exposed asset	≤50					0	2
	51-100					0	1
	>200					3	5
Future exposed asset rank	≤10	3	1			2	2
	11-20	3	0			1	2
	21-30	1	0			0	1
	>40	1	2			0	3
Damage due to hazard (billion US$)	≤0.5					0	4
	0.5-1					0	1
	1-5					1	2
	>5					2	1

Source: (ADB, 2010; BNPB, 2012; City-of-Copenhagen, 2011; City-of-New-York, 2007; Dircke, et al., 2010; DOCC, 2009; EPD, 2010; GLA, 2012; Grossi, & Muir-Wood, 2006; Yongjin, 2010)

Regarding the influence of risk magnitude, five factors are significantly related to the wetland protection measure. Besides, the city's rank based on future exposed asset is moderately correlated with this measure. Top ranked cities in terms of future exposed asset are more willing to exercise this measure.

Cities with large number of exposed population have adopted this measure. Similarly, cities with high risk in terms of current and future exposed asset are more willing to implement this measure. Moreover, cities threat experience appraisal can be considered in order to decide on ecological storm surge barrier. For this damage data has been collected for a particular devastating hazard that 11 precedent cities have already experienced. It is found that only those three cities have adopted this measure who experienced more severe damage than others.

Planning Regulation and Management

Under this approach four policies have been selected. Among them the decision of undertaking risk zoning policy can take place based on three variables. First, if cities are vulnerable to SLR especially in the future then those cities can impose zoning regulation according to risk factor. Then if the cities are relatively more vulnerability to the wind effect during cyclones, then risk zoning can reduce the wind exposure. Finally, the decision on risk zoning might be influenced by city's experience on severe flood hazard.

Table 5: Precedent cities status on planning regulation and management approach

Explanatory Variables	Categories / range	Risk zoning		Building regulation		Development control		Protection of critical facility	
		Adopted	Not adopted	Adopted	Not adopted	Adopted	Not adopted	Adopted	Not adopted
Average height from sea level (m)	0<h≤3					1	1	2	0
	3<h≤6					1	1	1	1
	6<h≤10					1	2	1	2
	h>10					0	4	0	4
Number of people living below 0.5m of sea level ('000)	≤50					0	3		
	50-150					0	1		
	150-300					0	3		
	>300					3	1		
Average rainfall (mm)	≤700			0	2				
	701-1400			2	2				
	1401-2100			2	2				
	>2100			1	0				
AAL by SLR (million US$)	≤50	2	2	1	3	0	4		
	51-200	1	2	1	2	0	3		
	>200	4	0	3	1	3	1		
AAL GDP ratio	≤0.01			2	5	0	7	2	5
	0.051-0.10			1	0	1	0	0	1
	>0.10			2	1	2	1	2	1
Wind damage index	0 to 10	5	2						
	11 to 20	2	0						
	21 to 50	0	1						
	51 to 100	0	1						
Current exposed population	≤500					0	4		
	500-1500					1	3		
	>1500					2	1		
Percentage of	≤10					1	6	1	6

Explanatory Variables	Categories / range	Risk zoning		Building regulation		Development control		Protection of critical facility	
		Adopted	Not adopted	Adopted	Not adopted	Adopted	Not adopted	Adopted	Not adopted
current exposed population	11-20					0	1	0	1
	31-50					1	0	1	0
	≥51					1	1	2	0
Current exposed asset	≤50					1	4		
	51-100					0	2		
	101-150					0	1		
	151-200					0	1		
	>200					2	0		
Future exposed population	≤500					0	3		
	500-1500					1	2		
	1501-2500					0	1		
	2501-5000					1	1		
	>5000					1	1		
Percentage of future exposed population	≤10					0	5	1	4
	20-Nov					1	1	0	2
	31-50					0	1	0	1
	≥51					2	1	3	0
Damage due to hazard (billion US$)	≤0.5	2	4	3	1	1	3		
	0.5-1	0	1	0	1	0	1		
	1-5	2	3	0	3	0	3		
	>5	3	3	2	1	2	1		

Data source: (ADB, 2010; BNPB, 2012; City-of-Copenhagen, 2011; City-of-New-York, 2007; Dircke, et al., 2010; DOCC, 2009; EPD, 2010; GLA, 2012; Grossi, & Muir-Wood, 2006; Yongjin, 2010)

Conclusion

It can be said that in a stable political situation, a city can decide to adopt various DRR policies based on geography and climate, hazard pattern, magnitude and experience. The analysis shows that among 10 policies, enhancing green area and adaptation measures do not depend on any of the selected influential variables. In most of cases these two measures have been perceived as supplementary and this might be the possible reason of not having any substantial variables. Also adaptation measures including flood insurance do not depend on any explanatory variables. Some may argue that insurance depends on the GDP of cities, which is to some extent true but some exceptional situation can be observed. To implement high-tech structural flood protection measures, cities need to have access to finance, but again it's a political decision. It depends on how a city is prioritizing its investments.

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