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Climate Resilience in the Greater Bay Area of China - The Role of Technological Innovation

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The article discusses climate-related vulnerability, adaptation and resilience issues of the Greater Bay Area (GBA) of China. First, it reviews key studies on past, current and future climate trends focusing on meteorological, climatological, hydrological, and geophysical hazards. Second, it surveys climate adaptation policies and plans already implemented and their effectiveness to identify what works and what does not and where the gaps are. Third, the discussion focuses on the drivers and barriers for the uptake of technological innovation for flood prevention and for deploying emergency responses. The article finds that technological innovation, while potentially diminishing climate vulnerability, its deployment got to grapple with drivers and barriers to its uptake that ought to be identified, addressed and removed or enhanced, accordingly.

"We live in an amazing place – in uncertain times"

(Benjamin Grant, SPUR, San Francisco Bay Area, USA)

Abstract

Article 7.1 of the Paris Agreement establishes that parties should aim at globally enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change. While many climate hazards and vulnerabilities are beyond territorial control, the preparedness to withstand and recover from them has to be delivered locally. This article analyzes climate-related vulnerability, adaptation and resilience issues of the Greater Bay Area of China (GBA), a deltaic area that has been identified by the Chinese government as an engine of economic development but has historically been vulnerable to flooding. After providing a contextual **introduction to the Greater Bay Area** project, the article, first, reviews key studies on past, current and future **climate trends** focusing on meteorological, climatological, hydrological, and geophysical hazards. **Second**, it surveys **adaptation policies and plans** already implemented in cities of the GBA to assess what works and what does not and where the gaps are. Third, the analysis then focuses on **the drivers and barriers for the uptake of technological innovation** such for flood prevention and for the deployment of emergency responses. The aim of this analysis is to **identify the opportunities and risks of innovation** in building future-ready local skills and citizen engagement for climate resilience. The analysis finds that given the ambitious plans for the GBA to contribute to the economic development of China, existing and projected vulnerabilities to climate hazards and their potential impact on the built environment and physical infrastructure, business and industry, energy supply, financial services, human health, water resources and biodiversity may not only hamper GBA development plans but also put its businesses and citizens at great risk. Technological innovation diminishes this vulnerability but drivers and barriers to its uptake must be identified and enhanced or removed, accordingly.

Keywords

Greater Bay Area of China; Climate Resilience; Floods; Technological Innovation

I. Climate Adaptation & Resilience

Art.7.1 of the Paris Agreement states that 'parties hereby establish the global goal on adaptation of enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change, with a view to contributing to sustainable development and ensuring an adequate adaptation response in the context of the temperature goal referred to in Article 2'.[1] Article 2 (a), in turn, states that the Paris Agreement aims to strengthen the global response to the thread of climate change by 'holding the increase in global temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change'.[2]

Thus, in the context of climate change, adaptation means actions that are to be taken to anticipate and prevent or reduce the risks and negative effects of global warming on human and natural systems. Such negative effects are felt in various ways such as in the security of water, the condition of human health, the endurance of biodiversity, and the stability of food production, and of urban infrastructure. These effects are related to physical changes such as increased temperatures, changes in rainfall patterns, raising sea levels, extreme weather events, and so on, all of which are disrupted as the climate changes causing heatwaves, floods, landslides, etc. Coastal and delta regions are more exposed to these effects as they have through history been favored locations for the development of cities which are sites of significant assets and international connections given their open access to sea which, to date, is the most significant means of movement of people and goods.[3]

[1] Paris Agreement, p.9 https://unfccc.int/sites/default/files/english_paris_agreement.pdf
[2] Ibid. p. 3
[3] Around 80 per cent of global trade by volume and over 70 per cent of global trade by value are carried by sea and are handled by ports worldwide. Review of Maritime Transport 2015 https://unctad.org/en/pages/PublicationWebflyer.aspx?publicationid=1374

As discussed in the next section, the Greater Bay Area (GBA) of China[4] is one of these areas where cities not only top the world rankings for container port volume[5] but also for vulnerability to sea level rise and coastal flooding.[6] Particularly, the GBA cities of Guangzhou and Shenzhen are highly exposed, ranking as 1 and 10, respectively, in risk to flooding.[7] Given their large populations and economic activity, losses may be significant. As the GBA tries to develop from a traditional manufacturing and trade area into one in which technological innovation will be key to its sustainability, this article addresses the potential for technological innovation in enhancing the GBA resilience to climate change, specifically, its resilience to flooding.

In the next Section II, an analysis of the GBA project as recently announced by the Chinese leadership is made. This is followed by a brief description of the characteristics of its 11 cities and a survey on current climate and non-climate published studies to identify the gap in knowledge about the vulnerabilities and strengths of the GBA. In the hope of filling that gap, a set of questions this article addresses are identified. The article then turns to an exposition about the GBA climate parameters as well as its geological and hydrological hazards. Responses to these hazards in the form of short-term emergency and long-term climate adaptation plans are analyzed for their adequacy while the impacts of hazards and responses are also discussed. The analysis is made within the context of the 'transformative approach to transformation' methodology which posits that 'the ecological conversion of industrial societies into a climate-compatible, resource-conserving and sustainable world economic order, requires far-reaching and manifold tasks to shape it, which, in their make-up are neither purely scientific and technological nor purely social or political'.[8] Section III, then, turns the discussion to what it means to design, test and learn from technological innovation, what the drivers and barriers for the uptake of technological innovation may be, and what are the opportunities and risks for climate resilience. This section ends with the impact that such innovation may have in managing floods. The paper concludes with Section IV where some recommendations are also made.

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[4] The Greater Bay Area (GBA) https://www.bayarea.gov.hk/en/about/overview.html

[5] Top 50 world container ports: Shenzhen Port (3), Hong Kong Port (6), Guangzhou Port (7) http://www.worldshipping.org/about-the-industry/global-trade/top-50-world-container-ports

[6] World Bank. 2013. Coastal cities that are at greater risk to flooding: Guangzhou (1); Shenzhen (10) http://www.worldbank.org/en/news/feature/2013/08/19/coastal-cities-at-highest-risk-flood

[7] Ibid.

[8] Heinrich Böll Stiftung. 2015. Transformation Research: Research for and on the 'Great Transformation' https://www.boell.de/sites/default/files/uploads/2015/04/transformation_research_juli2015.pdf

II. The Greater Bay Area of China

1. The Project

At its Report on the Work of Government during the 12th National Party Congress of 5 March 2017, the Chinese Central Government of the People's Republic of China (PRC) announced a plan to transform 11 cities in the Pearl River Delta, including the special administrative regions of Hong Kong and Macau and the special economic zone of Shenzhen, from traditional manufacturing and trade areas into high-end financial, technological innovation and manufacturing, commerce, and cultural areas of excellence under the collective name of the Greater Bay Area (GBA).[9] An excerpt from the Work Report reads:

'We will promote closer cooperation between the mainland and Hong Kong and Macao. We will draw up a plan for the development of a city cluster in the Guangdong-Hong Kong-Macao Greater Bay Area, give full play to the distinctive strengths of Hong Kong and Macao, and elevate their positions and roles in China's economic development and opening up. We have always had full confidence about ensuring lasting prosperity and stability in Hong Kong and Macao'[10].

The GBA plan was then accorded the status of key strategic planning in the PRC development blueprint (13th Five Year Plan 2016-2020) with a mission to: 'facilitate in-depth and organic regional integration, as well as drive coordinated regional economic development'. On 1 July 2017, four parties, the National Development and Reform Commission (NDRC), and the governments of Guangdong, Hong Kong and Macau signed a Framework Agreement laying out broad working principles: 'innovation, coordinated development, sustainable development, mutual benefits and livelihood improvement for citizens of the 3 jurisdictions, especially young people'.[11] The Framework Agreement also listed 6 broad areas of cooperation:

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[9] Xinhuanet. 2017. Full Work Report here: http://www.xinhuanet.com/english/china/2017-03/16/c_136134017.htm . Another Central Government-driven 'strategic' development within the GBA is the Shenzhen Qianhai district, a special economic zone designated for a US$45 billion development intended to transform the 15Km^2 area into a 'Manhattan of the Pearl River Delta'. Several architectural firms have been hired by China Resources Land to design office towers http://www.gpchicago.com/news/gp-wins-its-largest-commission-china/

[10] Excerpt from page 6 of the Full Work Report http://www.xinhuanet.com/english/china/2017-03/16/c_136134017.htm

[11] Bay Area Agreement https://www.bayarea.gov.hk/en/about/agreement.html

- *Infrastructure connectivity* including ports, airport clusters, motorways, rail and city trains, energy and water supply, information and communication networks;
- *Market integration* that includes the promotion of Closer Economic Partnership Agreement (CEPA)[12], the facilitation flow of factors of production, people and goods via smooth immigration and customs channels, and the development of a globally competitive environment that would entice the people in Hong Kong and Macau to live and invest in Guangdong;
- *Innovation and Technology* to transform R&D results into applicable technologies;
- *Development of modern industries* such as high-end and global value chain types;
- *Creation of a 'living circle'* for people by means of establishing an international education highland (Huizhou); a tourism education center (Macau); and an ecological conservation and green low carbon area in all of the GBA;
- *New strengths* by persuading Hong Kong and Macau to collaborate with Belt and Road Initiative (BRI)[13] countries[14] and having Guangdong, Macau and Hong Kong going global together.

Among these cooperation areas, for example, Hong Kong is committing specific contributions to the GBA such as establishing an innovation and technology hub, developing industries that are already Hong Kong's strengths, and fostering the flow of people, goods, capital and information. The Framework Agreement envisions that the channels of collaboration will not only be between governments but also via industry associations, think tanks, professionals and academics.

The Constitutional and Mainland Affairs Bureau (CMA) of the Hong Kong Special Administrative Region (HKSAR) hosting an informative GBA website[15] lists 12 policy areas of collaboration. Yet, reading the text under each of these policy areas, one finds that rather than highlighting common projects or areas of cooperation between, for example, Hong Kong and the GBA, the text simply spells what Hong Kong already has in place in relation to each of those policy areas. An, 'on-the-spot' qualitative assessment of each policy area shows what is stated and omitted in the CMA website as areas of cooperation (Table 1). This assessment is informative as to what the possibilities for further cooperation may be.

[12] Closer Economic Partnership Agreement https://www.tid.gov.hk/english/cepa/
[13] Belt and Road Initiative Basics https://beltandroad.hktdc.com/en/belt-and-road-basics
[14] Belt and Road Initiative Country Profiles https://beltandroad.hktdc.com/en/country-profiles
[15] The Greater Bay Area (GBA) https://www.bayarea.gov.hk/en/about/overview.html

Table 1. Qualitative Assessment of Policy Areas of Cooperation within the GBA: A Hong Kong Perspective[16]

Policy Area	Stated	Omitted
Innovation & Technology	Hong Kong has an *Innovation & Technology Bureau* and is promoting eight IT areas. The city has 4 of the top world 100 universities with 40 academicians in the Chinese Academy of Science (CAS) and the Chinese Academy of Engineering (CA of Eng). It also has 2 research clusters in the Science Park[17] providing finance to NGOs' start-ups. The *Mainland National Ministry of Technology* has signed MOUs with Hong Kong universities allowing them to access Mainland research funding. The Massachusetts Institute of Technology (MIT) and the Swedish Karolinska Institutet have established offices in Hong Kong and the Hong Kong Smart City Blueprint[18] has been published.	Any existing collaboration in the area of IT between Hong Kong and any of the other 10 cities of the GBA or among all 11 cities.
Financial Services	Hong Kong has an offshore renminbi (RMB) and the Shanghai-Hong Kong (SH-HK) Stock Connect is present here. The Shenzhen-Hong Kong (SZ-HK) Stock Connect northbound and southbound is also established in Hong Kong. China Mainland-Hong Kong has a Mutual Recognition of Funds and a RMB Qualified Foreign Institution Investor. Green Finance was announced in the HKSAR 2017 Policy Address and insurance schemes of some mutual recognition as well as the Bond Market are also available.	Other than some collaboration with Shanghai and Shenzhen, no specific financial services established in collaboration with the GBA are mentioned.

[16] Compiled by the author of this article from Ibid. https://www.bayarea.gov.hk/en/about/overview.html
[17] Science Park Hong Kong https://www.hkstp.org/en/our-stories/technology-and-innovation/
[18] Smart City Blueprint Hong Kong https://www.smartcity.gov.hk/

Transportation & Logistics	List of infrastructural connections available in cities of the GBA such as aviation; port development and logistics; maritime; and cross-boundary infrastructure.	No specific overall transport and logistics strategy or future plans are mentioned.
Close Enhanced Partnership Agreement (CEPA) & Professional services	Zero tariffs on Closer Enhanced Partnership Agreement (CEPA) listed goods are announced as well as liberalized services. For example, Hong Kong professionals can get Mainland professional qualifications and some Hong Kong law firms have partnerships with the Mainland. Also there is investment protection and facilitation in the Mainland.	Other than via CEPA, no mention is made of specific professional collaborations among cities in the GBA.
International Legal & Dispute Resolution Services	GBA plans encourage the use of Hong Kong arbitration and mediation services and of the Hong Kong-based Apology Ordinance[19] which has been in force since end of 2017.	No mention is made of legal services in collaboration with GBA cities.
Clearance Facilitation	People exchange (use of e-channels) and the establishment of face-recognition and smart-departure are mentioned as well as the setting of an E-Lock Scheme, etc. This section lists existing and some new facilitative connections with GBA cities.	---
Medical Services	Hong Kong registered medics can practice short-term in the Mainland and a HKU-SZ hospital, wholly invested by the Shenzhen government but managed by HKU, has been established. A pilot scheme to serve Hong Kong elderly living in China to access HKU-SZ hospital is in place demonstrating some collaboration within the GBA with regards medical services for all 11 cities' citizens.	---
Education	Hong Kong children can apply for free education in SZ public	No substantial mutual collaboration with GBA cities is in

[19] Apology Ordinance Cap 631 https://www.elegislation.gov.hk/hk/cap631

	schools on a point basis. And they can also apply to public schools in the cities of Guangzhou, Zhuhai, Dongguan, and Zhongshan through a point system. A voluntary sister school system has been put in place by which local Hong Kong schools can establish exchanges with schools in the GBA.	place, i.e. no Hong Kong schools are establishing branches in GBA, etc. Some facilitative mechanisms for Hong Kong children to study in GBA cities are in place but no mention is made of an overall education strategy for the whole of the GBA.
Arts, Culture & Creative Industries	The building of the West Kowloon Cultural District in Hong Kong is mentioned but nothing is said about how this may enhance the access of GBA citizens' to arts and culture. Hong Kong has identified 8 creative industries (advertising, architecture, design, digital entertainment, film, music, publishing and printing, television) it wishes to promote without mentioning whether these initiatives are platforms of collaboration with the GBA cities.	A Biennale of Urbanism/Architecture in Hong Kong and Shenzhen has been held regularly but no mention is made as to how this may potentially be extended to other cities of the GBA.
Tourism	Hong Kong has a number of tourism sites such as the Disneyland and Ocean Park themed parks as well as it offers a series of diversified travel products and access to the new Kai Tak Cruise Tourism facility.	No specific collaboration with the GBA, like, for example, selling travel packages to international tourists that would include several GBA cities' experience, is mentioned.
Environmental Protection & Sustainable Development	Agreements on air and water quality and on cleaner production have been made between Hong Kong and Guangdong.	Despite the GBA vulnerability to climate change, nothing on climate mitigation, vulnerability, resilience and adaptation measures that are being taken in the region as a whole are mentioned.[20]
Youth Employment	Funding for youth internships in China are available in Hong Kong as as are thematic youth internships at institutions such as the Palace Museum,	Nothing is said about potential Hong Kong youth employment in the GBA other than the Mainland internships offered to Hong Kong students nor

[20] The Outline Development Plan mentions the importance of flood prevention and the strengthening of seawalls and river banks, drainage systems, storm surge prevention and emergency response https://www.bayarea.gov.hk/filemanager/en/share/pdf/Outline_Development_Plan.pdf Ch. 5, Section 4, para. 2, p. 25.

	Woolong National Nature Reserve, Dunhuang Caves and the Chinese Academy of Science (CAS) none of which are located in GBA cities. Corporate internships in the GBA and in Belt and Road Initiative countries and other overseas localities are also mentioned as well as youth exchanges in Mainland.	other youth employment schemes across all GBA cities.

To speed up potential collaboration, two facilitative measures have been put in place:

- Residence Permits for Hong Kong, Macau and Taiwan residents (August 2018) giving successful applicants the right to employment, education, medical care, travel, and financial services;
- Other measures: on education employment, and daily life access to services.

Following the 1 July 2017 announcement, an Outline Development Plan for the GBA[21] was published in February 2019 providing a more detailed background to the project. This includes, its guiding ideology, spatial layout, desired development as an innovation and technology hub, infrastructure connectivity, industrial systems, ecological conservation, and quality living and cooperation platforms. No mention is made in the plan about the GBA's climate vulnerability and resilience, though, as mentioned, the necessity for flood prevention is included in the chapter on infrastructural connectivity.[22]

With a combined GDP of USD1,345 billion, a population of 64 million, and the completed projects of the Zhuhai-Hong Kong-Macau bridge, the Guangzhou-Shenzhen-Hong Kong Express Rail Link, and the Liantang/Heung Yue Wai Boundary Control Point, the area's connectivity and potential contribution to China's and the world's future economy is enormous.

[21] Ibid.
[22] Ibid.

2. Exiting Research and Knowledge Gaps

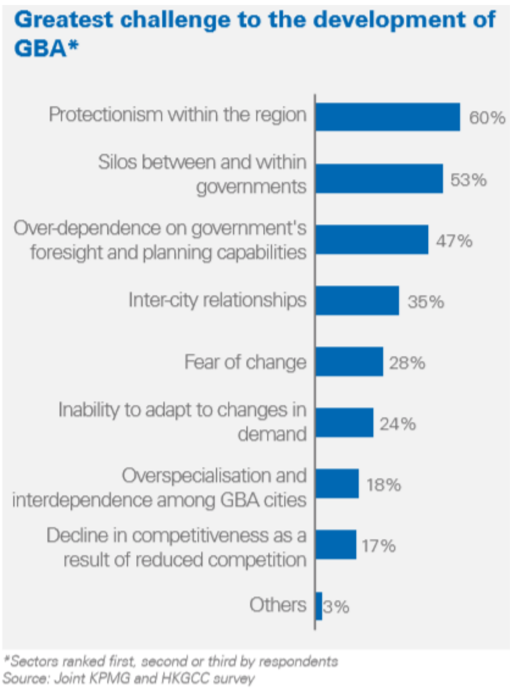
While the above is what the official documents state about what the GBA is expected to be like and what Hong Kong's potential contributions to it may be, **unless this low-lying delta region recognizes its vulnerability to climate change and puts in place effective adaptation strategies to support its sustainable development and ambitious goals, potential disruption to these plans are anticipated. A clear understanding of the level of climate-related vulnerability, resilience, and adaptive capacity of the GBA is required.**

What knowledge do existing studies provide in this respect?

2.1. Economic-related research

Hong Kong Chambers of Commerce, the Trade Development Council, and management consultants (i.e. KPMG) have surveyed relevant stakeholders on the GBA plans coming to conclusions on the drivers and barriers potentially affecting the GBA project (see Fig. 1). For example, companies already operating in the GBA cities, highlight the ease of access to robust infrastructure and abundant and motivated talent as factors drawing them to invest. But they also identify entrenched practices such as protectionism, lack of coordination among different policy sectors, and declining competition as challenges to be reckoned with. As with the official documents, challenges to the GBA posed by climate change are not mentioned in any of these surveys. Figure 1 presents the results of the KPMG survey.

Figure 1. Greater Bay Area Key Challenges[23]



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[23] Joint KPMG and Hong Kong General Chamber of Commerce (HKGCC) Survey on the GBA https://assets.kpmg/content/dam/kpmg/cn/pdf/en/2018/04/a-lens-on-the-greater-bay-area.pdf

Informative is the fact that KPMG interviewed managers with significant presence in the GBA such as China Resources, Swire, SF Express, China Merchants Group, Twinkle Baker Décor, and Tencent. It also identified the potential beneficiaries of GBA.[24] According to the interviewees, the sectors and particular industries likely to benefit from the GBA project are:

- 68% Trade and logistics (HK, SZ): shipping, delivery services
- 62% Financial services (HK): international finance, offshore RMB
- 60% R&D (SZ)
- 52% Professional services (HK): dispute resolution
- 28% Manufacturing sector (SZ): traditional and innovative
- 28% Tourism and Exhibitions (HK, Macau)

It is understood these results are based on the assumption that the sectors that are to benefit most are those with the greater potential for growth. If climate change is not factored in the risk analysis, these sectors will also be those with the greatest potential for disruption and consequential losses.

As per Table 2, the economic profile of the PRD/GBA and the composition of its GDP has changed since the area first benefitted from the 'open-door policy' of China (1978) with the tertiary sector now bringing in most of the revenue.

Table 2. Composition of the Pearl River Delta/ Greater Bay Area GDP[25]

Industry	1980	2008	2016
Primary Industry (%)	25.8	2.4	1.8
Secondary Industry (%)	45.3	49.9	42.1
Tertiary Industry (%)	28.9	47.7	56.1

[24] Ibid. p. 14 https://assets.kpmg/content/dam/kpmg/cn/pdf/en/2018/04/a-lens-on-the-greater-bay-area.pdf

[25] Guangdong Statistical Yearbook. 2016. In Hong Kong Trade Development Council http://china-trade-research.hktdc.com/business-news/article/Facts-and-Figures/PRD-Economic-Profile/ff/en/1/1X000000/1X06BW84.htm

2.2. Climate adaptation-related research

Previous climate adaptation-related work identifies some of the **physical vulnerability** to the Pearl River Delta (PRD) people and assets posed by climatic changes. For example Nicholls et al. 2007,[26] rank Guangzhou city, the capital of Guangdong province, as number two among top 20 cities whose significant assets are exposed to the **risk of flooding.** In the same league table, Hong Kong ranks as the 9th most vulnerable city. Other studies find that trends of increasing **temperatures, rainfall incidence and intensity, typhoons, storm surges and sea level rise** are rendering the PRD/GBA very vulnerable.[27] This latter work also discusses the various **socio-political and governance challenges** posed when trying to integrate flood risk management and climate change in spatial planning to ensure the sustainable development of the PRD/GBA.[28] The lack of an integrative approach to render the PRD climate-proof [29] is found to be the main obstacle in making the PRD adaptable to climatic changes.

What has not been done is to put all this research in the *theoretical context of transformative research* (see below) in the Greater Bay Area. This analysis in this article links the concepts of transformation 'the ecological conversion of industrial societies into a climate-compatible, resource-conserving sustainable world and economic order'[30] and transformative research an approach to 'investigation that brings together various individual scientific perspectives such as science, engineering, public policy and integrates them in the light of transformation-relevant perspectives'.[31]

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[26] Key references are: Nicholls, R. et al. 2007, 'Ranking of the world's cities most exposed to coastal flooding today and in the future'. In OECD environment working paper n.1 (ENV/WKP(2007)1). Paris: OECD. The Pearl River Delta Region is a wider area than the Great Bay Area which comprises 11 of its cities only.

[27] Hong Kong Observatory, Climatological Information Services http://www.hko.gov.hk/cis/climat_e.htm ; Climate Change Report HKSAR 2015 https://www.enb.gov.hk/sites/default/files/pdf/ClimateChangeEng.pdf

[28] Francesch-Huidobro et al. 2017. 'Governance challenges of flood-prone delta cities: integrating flood risk management and climate change in spatial planning', *Progress in Planning*, 114 (2017), 1-27

[29] Climate-proof is a concept developed by the Dutch Rotterdam Climate Initiative http://www.rotterdamclimateinitiative.nl

[30] Heinrich Böll Stiftung. 211. World in Transition: a Social Contract for Sustainability 2011 https://www.boell.de/en

[31] Ibid.

2.3. The Cities

Figures 3 and 4 show the location of the 11 cities included in the GBA plan and its key infrastructure. The cities' geographic and hydrological patterns are challenging not only due to the confluence of three major rivers, East (Dongjiang), West (Xijiang) and North (Beijiang) (Figure 4) and to the numerous canals that transverse them, but also to their location in a floodplain that is only about 2 meters above sea level which renders it vulnerable to regular diurnal tides as the average peak tidal level is about 2.02 meters. Thus, on the face of it, the potential of fluvial, pluvial and coastal flooding and landslides render the GBA vulnerable.

Figure 3. Map of the 11 cities in the Great Bay Area of South China and their key infrastructure[32]

Figure 4. Extract of map locating the Dong (East), Bei (North), and Xi (West) Rivers of the GBA[33]

[32] Multimedia South China Morning Post.
[33] Rivers of the Greater Bay Area http://www.lahistoriaconmapas.com

The area is also affected by increasingly more frequent and severe typhoons. For example, typhoons Hato in 2017 and Manghkut in 2018 inflicted serious damage to Hong Kong, Macau and the southwest of the Guangdong Province (Toishan). Swiss RE estimated daily income losses of US$627 million after Manghkut brought Hong Kong to a standstill for two consecutive days (16 and 17 September).[34] Land use changes in the form of more built-up areas have also increased from 4.41% in the 1980s to 20.61% in the late 2000s. This has been compounded with a population growth from 23.3 million in 1982 to 68 million in 2018 which is eventually expected to decline to 63 million in 2020.[35]

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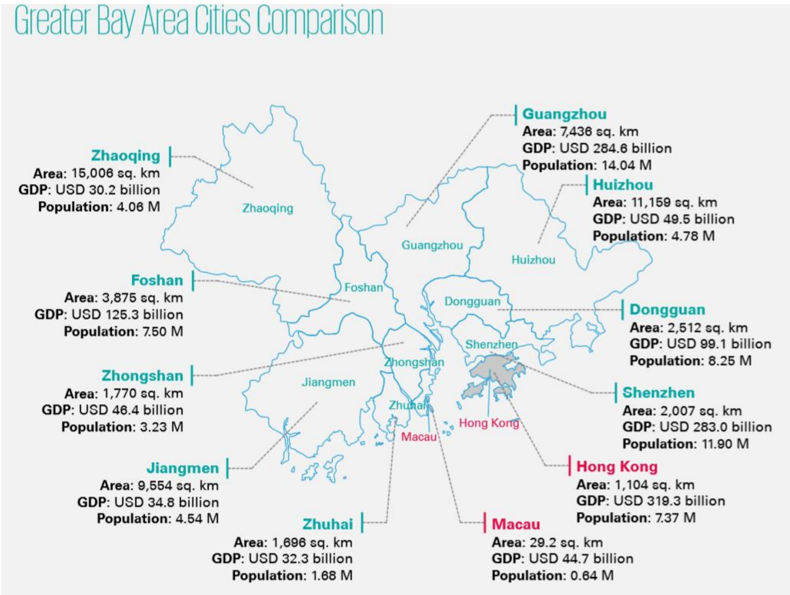
[34] Swiss RE parametric typhoon business interruption http://www.artemis.bm/blog/2017/07/21/swiss-re-pioneers-parametric-typhoon-business-interruption-cover/

[35] Yang et al. 2015. 'Climate-related flood risks and urban responses in the Pearl River Delta, China. *Regional Environmental Change,* 15(2), 379-391, Supplementary material p.1.

Together, these changes expose more people and infrastructure to climate-related hazards increasing the GBA's vulnerability and the need for adaptive capacity. Figure 5, shows the exposed area, population, and assets of each GBA city.

Figure 5. Greater Bay Area Cities Key Data (2016)[36]



Source: Fung Business Intelligence, Data as at 2016

2.4. The Questions

The line of inquiry in this article is guided by the following questions:

- What are the observed and projected climate changes for the GBA?
- Based on the above, what are the **key sectors and processes** (existing and planned) of the **vulnerability assessment** of the GBA?
- What existing adaptation infrastructure and policies are in place to protect vulnerable sectors, processes and facilities? How effective have this infrastructure and policies been, so far?
- How do **theories and methodologies** linking the goal of *transformation* to the process of *transformative research* help us understand the impact of GBA's vulnerability and enable cross-sector adaptation?
- How will transformative research help overcome possible **obstacles** and enable **drivers** for transformation and the uptake of technological innovation?

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[36] Fung Business Intelligence, Feb 2019 https://www.fbicgroup.com/sites/default/files/GBA.pdf

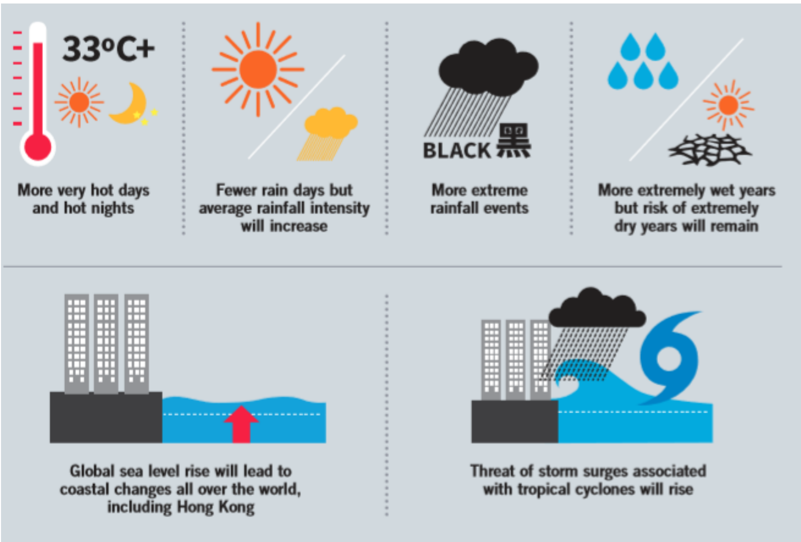
3. Climate Change in GBA

To ascertain levels of vulnerability, an understanding of the current and future climate trends of the GBA is needed. Studies show that both geological and hydrological hazards in the area are significant. These are discussed after an exposition of the climatological parameters.

3.1. Climatological parameters

The Greater Pearl River Delta Weather website[37] jointly hosted by the meteorological authorities of Hong Kong, Macau and Guangdong provides weather forecasts (not climate) of cities in the region. Other than this weather information, no GBA climate data is available (at least in English). Thus, in this analysis the Hong Kong Climatological Information Services data[38] is used as proxy to understand climate trends in the GBA. Figure 6, shows that temperatures are raising, rainy days are decreasing but precipitation intensity is increasing, extreme precipitation is becoming also more frequent and extremely wet years are on the rise while extremely dry years will still occur. Global sea levels will affect the very long coast of the GBA and so will storm surges associated with severe tropical cyclones.

Figure 6. Climate Change Trends in the GBA[39]



[37] Pearl River Delta Weather http://www.prdweather.net/forecast.htm
[38] Hong Kong Observatory http://www.hko.gov.hk/cis/climat_e.htm
[39] Hong Kong Climate Change Report 2015 https://www.enb.gov.hk/sites/default/files/pdf/ClimateChangeEng.pdf

In addition to the climate data available in the official meteorological agencies, historical and future climate trends can also be accessed from existing analyses[40] which, in turn, have collected data from the Hong Kong Observatory (HKO), from tide gauges at Denglongshan and Hengmen, from the Guangdong Statistic Yearbook (2011 & 2012) and from academic publications, for example, Yang et al. 2015 and He and Yang 2011[41] and Kong et. al 2010.[42] In particular, the analysis of precipitation in the Pearl River Delta (PRD) area (now known as the GBA) from 1957-2009 is based on China's Daily Terrestrial Climate Dataset in the China Meteorological Data Service Centre.[43]

Given the above climate parameters, which are the significant climate-related hazards impacting the GBA? The following focuses on geological and hydrological (coastal, fluvial and pluvial floods) as these are significantly threatening the success of the GBA project.

3.2. Geological hazards

In their discussion paper Ma et al. (2018), highlight the major geological hazards of the delta.[44] These 'consist of collapse, landslide, ground subsidence, karst collapse, water and soil loss, and seawater intrusion'[45] as represented in Figure 7 below. As of 2014, there were 52 large-scale collapses, 35 landslides and 5 debris flow in the area. In addition, there were also 129 subsidence vulnerable areas.[46] Water and soil erosion are also widely distributed in Longgan District, Shenzhen City and Huadu District and Guangzhou City covering 4.8% of the total land area. Seawater intrusion is also an issue.[47] Land use has been changing from cultivated and garden plots to urban construction.

[40] Weng 2007; Yang et al. 2015; Hong Kong Climate Report 2015 https://www.enb.gov.hk/sites/default/files/pdf/ClimateChangeEng.pdf

[41] Yang et al. 2015. 'Climate-related flood risks and urban responses in the Pearl River Delta, China', *Regional Environmental Change*, 15(2), pp.379-391. https://doi.org/10.1007/s10113-014-0651-7 ; He and Yang. 2011. 'Urban development and climate change in China's Pearl River Delta'. *Lincoln Institute of Land Policy Land Lines*. July 2011

[42] Kong et al. 2010. 'Estimation of peak water level in Pearl River Estuary'. *Yangtze River* 41(14), pp.2024 (In Chinese)

[43] National Meteorological Information Centre. China Data Service Centre https://data.cma.cn/en/?r=data/weatherBk

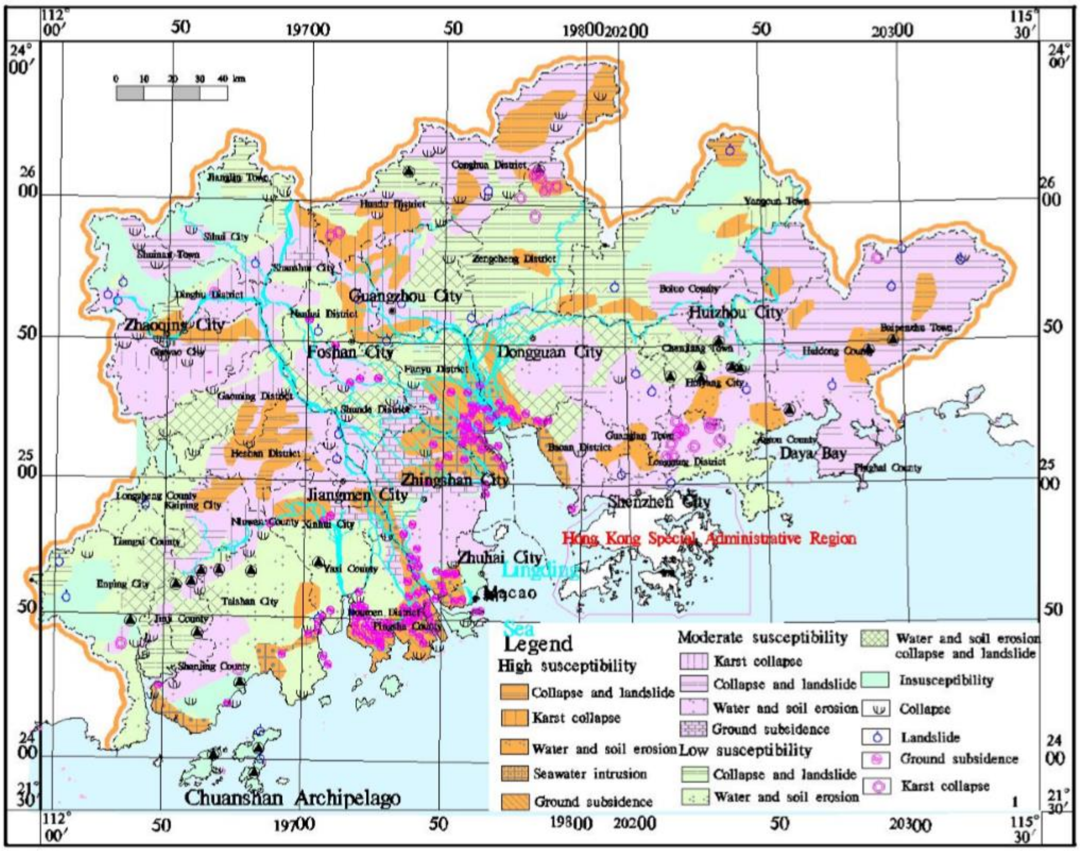
[44] Ma et al. 2018. 'The susceptibility assessment of multi-hazard in the Pearl River Delta Economic Zone, China' *Natural Hazards Earth Systems Discussions* (under review version) https://www.nat-hazards-earth-syst-sci-discuss.net/nhess-2018-104/

[45] Ibid. p. 9

[46] Ibid.

[47] Ibid. p. 10

Figure 7. A comprehensive susceptibility map of geological hazards in the GBA (data from the HKSAR is excluded in this map)[48]



Thus, the main hazards' susceptible events are:

- *Collapses and landslides:* in the north of Conghua District, Heshan City (where the HKJC has just opened stables and a training track for race horses!)
- *Karst (soluble rocks) collapses:* Huada District and Nanhai District of Guangzhou City and Zhaoqing City. Buluo County in Huizhou City.
- *Water and soil erosion:* Guanlan Town, Longgan and Huiyang Districts, Heshan City and eastern areas of Taishan City.
- *Sea water intrusion:* Zhongshan City, Jiangmen City, Nansha District and Doumen District.
- *Ground subsidence:* Fanyu District and Niuwan Town and Pingsha Town.

[48] Ibid. p. 19

Other than composition conditions such as the topography, stratigraphic lithology (layered rocks), and geological structure that are inherent to the area's geology and, thus, not climate change-related, factors such as heavy precipitation to which the GBA is prone from June to September and the consequential strong surface runoff that increases pore water in soil reducing its shear strength, are causes of geohazards resulting in slope destabilization and collapse. Other than precipitation, the cutting of slopes and removal of vegetation to construct buildings changes the stress of the original balance triggering collapses and landslides. Large over and underground constructions apply static load on foundations eventually triggering ground collapse and subsidence. The study undertaken by Ma et al. shows that at least 16.5% of the GBA is highly susceptible to geohazards.[49]

3.3. Hydrological hazards

Strong monsoons, dense river nets, the significant effects of erosion and deposition, and rapid economic development and population growth are fragmenting the GBA natural environment rendering it vulnerable of which flood is the most significant hazard. Traditional dike-pond infrastructures and modern hydraulic engineering (dams and reservoirs) upstream largely prevent fluvial floods while pluvial and coastal floods are a regular occurrence of concern to governments and other stakeholders, most significantly, businesses. Figure 8 shows examples of current and projected sea level rise trends during typhoons that also bring about significant storms surges (Fig. 8 refers to Hong Kong only). As one observes from the arrows, the return period for sea level rises above the chart datum are getting shorter. 3.8 m rises which used to occur every 10 years are now occurring annually.

Figure 8. Recent Hong Kong Historical Extreme Sea Level and Storm Surges[50]

Return period (year)	Extreme sea level above Chart Datum (m)				Historical Typhoons bringing significant storm surges to Hong Kong (Maximum sea level above Chart Datum at Victoria Harbou)
	Current	Sea level rise reaching 0.26m in 2021-2040	Sea level rise reaching 0.53m in 2046-2065	Sea level rise reaching 1.07m in 2081-2100	
1	2.7	3.0	3.2	3.8	T. Hagupit in 2008 (3.53m)
2	2.9	3.2	3.4	4.0	
5	3.1	3.4	3.6	4.2	T. Wanda in 1962 (3.96m)
10	3.3	3.6	3.8	4.4	Typhoon in 1937 (4.05m)
20	3.4	3.7	3.9	4.5	
50	3.5	3.8	4.0	4.6	

Projected changes in return values of extreme sea level events in 2021-2040, 2046-2065 and 2081-2100 under the high GHG concentration scenario

[49] Ibid.

[50] Hong Kong Climate Change Report 2015 https://www.enb.gov.hk/sites/default/files/pdf/ClimateChangeEng.pdf

Table 2a summarizes the results of studies on recent and future trends of climate changes in the GBA.

Table 2a. Recent and future climate changes in the PRD/GBA[51]

Source	Region	Recent trend			Future trend		
		T	P	Sl	T	P	Sl
Yu et al. (2007)	Guangdong	↑	0	↑	↑	↑	↑
Tang et al. (2008); Huang and Zhang (1999)	Macau	-↑	-↑	↑-	-↑	-↑	↑-
Zhang et al. (2009); Fischer et al. (2011); Chen (2012); He and Yang (2011)	PRD	-↑↑-	00-↑	----	----	----	----
Li (2011); SOA China (2011); Shi et al. (2008); Huang et al. (2004)	PRD	----	----	↑↑↑↑	----	----	↑↑↑↑
Du and Li (2008); Li et al. (2012)	South China	-↑	-↑	--	↑↑	↑↑	--
Wang et al. (2011)	East River	-	-	-	-	↓	-
Hong Kong Observatory (2012); Ginn et al. (2010)	Hong Kong	↑↑	↑↑	↑↑	↑↑	↑↑	↑↑
Li (2009)	PRD	↑	0	-	↑	↑	-
Own analysis using observation records	PRD	↑	0	↑	-	-	-
Own analysis using reanalysis and modeling	PRD	0	↑	↑	↑	0	↑

T: Temperature; P: Precipitation; Sl: Sea level.
↑: increase; ↓: decrease; 0: no significant change; -: no result in mentioned source literature. Combinations of the symbols indicate results in different sources, e.g. -↑ means the 1st reference doesn't give result on the item and the 2nd reference gives a result of increase.

In a fascinating historical study undertaken by Qihao Weng (2007)[52] on river basin management in the PRD (GBA), dike building, land reclamation and dike-pond systems are identified as the key infrastructures inhabitants of the Delta have relied upon since it began to be more permanently settled about 1,300 years ago during the Tang dynasty (618-907 AD). Before then, the two Lingnan provinces of Guangdong and Guanxi had been shunned by northern Chinese due to malaria infested conditions.

Located between coordinates 21.4°N- 23°N (latitude) and 112°E-113.2°E (longitude), the 17,200 Km^2 Delta has average temperatures of 21-23°C, an average precipitation of 1600-2600 mm/y, and an exposure to hazards such as intense precipitation (Apr-Sept) and typhoons (June-Oct). The main delta (Pearl- Zhujiang) is made up of 3 sub-deltas (Xijiang (West), Dongjiang (East) and Beijiang (North) which were formed about 40,000 years ago. To the East, West and North, the delta is surrounded by 500 m above mean sea level (msl) hills, while hills of between 100-300 m above mean sea level (msl) can be found within the delta. The rest of the delta is made up of high and low plains 0.5-0.9 m above msl, waterlogged land, dike-pond land serving agriculture and aquaculture purposes, and a drainage system. Rivers discharge silt and water to the South China Sea via 8 estuaries (gates).

[51] Yang et al. 2015. 'Climate-related flood risks and urban responses in the Pearl River Delta, China', *Regional Environmental Change*, 15(2), pp.379-391. Supplementary material, p. 5 https://doi.org/10.1007/s10113-014-0651-7

[52] Weng, Q. 2007. ,'A historical perspective of river basin management in the PRD of China' *Journal of Environmental Management*, 85(4), pp. 1048-1062 https://www.ncbi.nlm.nih.gov/pubmed/17240525

The increase in population that began around the year 618 AD brought about a very rapid increase in the building of low lying dikes for cultivation (paddy fields) as well as premature land reclamation on soft silt. Together, this sharply increased flooding frequency. 'Enclosed fields grew, river channels became longer and shallower, and channel gradients were reduced resulting in rivers easily silting up. Draining off floodwater slowed down, and the water table rose. Human activity had adversely affected the environment'.[53]

As shown in Table 2b,[54] the incidence of flooding increased as populations grew and higher ground was no longer sufficient for cultivating the food needed. The return period of floods also changed with floods that had been characterized as one in a 100-year occurring in shorter return periods. For example, Nanhai flooded 110 times between 810-1985 AD, an average of 10 times annually. The June 1885 floods were unprecedented and brought about great loss of life economic loss.[55]

Dike building bringing about greater accumulation of silt also promoted the growth of the delta seawards to as much as 10 m per year during the Tang dynasty which may have been moderated by a period of sea level decline that promoted erosion rather than siltation. But the seawards growth eventually increased to as much as 20 m during the Song (960-1279 AD), Yuan (1279-1368 AD) and Ming (1368-1644 AD) dynasties.[56] These seawards extensions of sandy fields and beaches created new opportunities for land reclamation to which landlords applied themselves diligently hoping to reap good returns from the new created land. Technologies applied during the Ming dynasty were not very different to those applied today: stone and boulders to slow the speed of water flow promoted the deposition of sediments. Reclamation continued during Qing (1644-1911 AD), the plantation of reeds at river mouths sped up siltation but at the expense of flooding. This has continued to these days 'posing a great threat to flood prevention, water logging discharge, irrigation, and coastal ecosystems'.[57]

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[53] Ibid. p. 1055 https://www.ncbi.nlm.nih.gov/pubmed/17240525
[54] Ibid.
[55] Disaster History.org http://www.disasterhistory.org/guangdong-flood-1885-3
[56] Ibid.
[57] Weng, Q. 2007. ,'A historical perspective of river basin management in the PRD of China' *Journal of Environmental Management*, 85(4), pp. 1048-1062 https://www.ncbi.nlm.nih.gov/pubmed/17240525

Other than dike building and land reclamation, dike-pond landscapes have historically been a key infrastructure of the delta. Low-lying lands inside the dikes were excavated to form ponds. The mud from the excavation was placed on top of the dikes to grow plants such as mulberries, sugar cane, lychees, etc. Carps were raised in the ponds. This infrastructure was well-adapted to the delta's flood-prone low lying areas. It not only improved the ability of storing floodwater and lowering the groundwater table, but also optimized agricultural production, increased profits and acted as reservoir in years of drought.[58] Yet, the gradual decline in the maintenance of all these infrastructures, especially after the rapid urbanization of the delta in the past 40 years, has meant shrinkage of agricultural land, upstream deforestation and soil erosion, silting up of river channels, flooding and the decline of water surface in the estuaries. In addition, although blessed with abundant rainfall, cities such as Guangzhou, Shenzhen and Zhuhai have been suffering drought.[59]

[58] Ibid. p. 1059
[59] China.org reported drought to 84 cities and counties of the Guangdong Province in 2004 http://china.org.cn/english/environment/111466.htm

Table 2b. Historical Floods in the PRD[60]

A statistics of floods in the Pearl River Delta (*source*: Yuan, 1992)

County	Song dynasty (960–1279)	Yuan dynasty (1279–1368)	Ming dynasty (1368–1644)	Qing dynasty (1644–1911)	Republic of China (1911–1949)	P.R. China (1949–)	Data period
Baoan 1981	—	—	—	2	1	4	1660–1981
Dongguan 1987	1	3	18	20	16	12	812–1987
Guangzhou 1983	—	—	5	9	3	7	975–1983
Heshan 1983	—	—	11	31	5	5	1422–1983
Nanhai	—	—	26	56	16	12	810–1985
Panyu	—	—	3	12	5	6	996–1985
Sanshui 1915	—	—	12	18	2	—	1535–1915
Shunde 1983	—	—	16	11	36	11	1448–1983
Xinhui 1985	—	—	2	7	9	8	1516–1985
Zhongshan 1987	—	1	9	5	8	6	1199–1987

The historical development of the Delta serves to understand the type of land conditions we are dealing with when new development projects such as the GBA are being rolled out in an era of climate change. Assessing the vulnerability and resilience of the GBA has to take account of these land conditions and of more recent adverse modifications.

Contemporary studies such as Rebecca Nadin's *Climate Risk and Resilience in China* (2016)[61] which includes Guangdong Province, draw attention to the impact climate change is having on people and sectors because of the rate of socio-economic development, migration, land-use change, pollution and urbanization. These impacts are exacerbated by more intense and frequent weather hazards, Nadin argues. Her work is based on the four-year study *Adapting to Climate Change in China (ACCC)* arguing for the need to: (a) develop regional climate models to find impacts on key industries and disaster risk; (b) develop a methodology to integrate risk assessment into national and provincial level planning processes; (c) assess the effectiveness of current adaptation policies and measures for rapid and slow onset events; (d) study options for risk transfer, financial mechanisms, and institutional arrangements to reduce exposure to loss and damage; (e) raise awareness and build capacity among disaster managers, local governments and communities.

Francesch-Huidobro et al. 2017 study, *Governance Challenges of Flood-prone Delta Cities: Integrating Flood Risk and Climate Change in Spatial Planning,*[62] is a comprehensive analysis of the spatial planning strategies of two of the GBA cities, Hong Kong and Guangzhou. The study also investigates how flood risk and climate adaptation are integrated in urban spatial planning strategies, and what flood risk management approach works.

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[60] Weng, Q. 2007. ‚'A historical perspective of river basin management in the PRD of China' *Journal of Environmental Management*, 85(4), pp. 1048-1062 https://www.ncbi.nlm.nih.gov/pubmed/17240525

[61] Nadin, R. 2016. Climate Risk and Resilience in China https://www.crcpress.com/Climate-Risk-and-Resilience-in-China/Nadin-Opitz-Stapleton-Yinlong/p/book/9781138818842

[62] Francesch-Huidobro et al. 2017. 'Governance challenges of flood-prone delta cities: integrating flood risk management and climate change in spatial planning', *Progress in Planning*, 114 (2017), 1-27

The study found that, first, the capacity of governments to steer and coordinate spatial and flood management activities is crucial in addressing climate-related risks. It also found that cities such as Hong Kong and Guangzhou are affording very low priority to climate adaptation in their political agendas.

Second, the study found that even when some individual cities such as Hong Kong have climate-related adaptation measures in their agendas, these are piecemeal (drainage system, water supplies, landslip control, etc). This finding is corroborated by the absence of an overall climate change-related information in the official GBA project documents. Paraphrasing Michael Bloomberg at the September 2018 Climate Summit, 'if you can't measure it, you can't manage it', if you don't have it in the agenda, you won't implement it!

Third, attitudes and approaches to flood risk management in different cities tend to differ. For example, if flood risk is universally recognized as the probability of a flood occurring multiplied by the expected loss by flooding, Hong Kong ad Guangzhou recognize it instead as drainage, water security and slope protection issues rather than as climate-adaptation matters with, potentially, many co-benefits. The GBA project's related documents do not recognize flood risk at all.

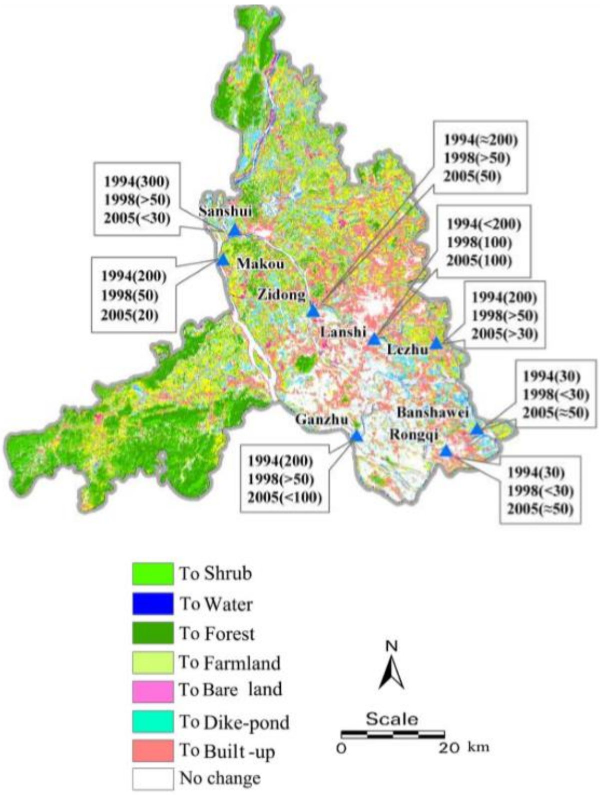
Fourth, a city's recognition of climate-related risks, vulnerability and consequential impacts is highly dependent on national administrative traditions and organizational structures. The GBA, not only includes two special administrative regions with totally different legal and administrative traditions from those of the PRC, but also a built-from-scratch special (artificial) economic zone, and a series of cities that until not long ago were rice fields and fish ponds. As recognized in the KPMG survey, the silo-effect between and within governments in the region is believed by 53% of respondents to be one of the greatest challenges to the success of the GBA project.

Finally, the way a city is planed determines the vulnerability and exposure of its population and assets to flood risk, this even when high engineering standards are applied, as it is the case in Hong Kong, to the mitigation of landslips in very steep and over-built terrain. Hard-engineering approaches to mitigate vulnerability have risks of their own. They tend to have a negative impact on the natural environment and water systems. It is not clear at the moment how the new cities on the mainland side of the GBA have been planned other and to what standards. Hong Kong has, by necessity and design, very high geotechnical standards when it comes to the maintenance of its slopes and walls.

All these hydrological hazards are present in the GBA but have not been considered in information packages and promotional material intended to attract high-end talent and significant investment to the GBA. Thus, the consequences of the disruption to sectors in particular and the overall trade flows in general are not being considered.

As an illustration, Figure 9 powerfully demonstrate the relationship between land use changes and the occurrence of extreme flooding which has increasingly shorter return periods in, for example, the Foshan area of the GBA. For example, extreme flooding in Makou was until 1994 occurring once every 300 years, by 2005, a severe flood is expected to occur in the district every 30 years or less.

Figure 9. Land use change 1988-2003 and floods (return periods/number of years in brackets) [63]



3.4. Responses: emergency & climate adaptation policies

If such are the potential, though often unrecognized climate-related hazards, what responses are in place in the individual cities from which to take reference for what could be a GBA-wide climate adaptation strategy?

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63 Zhang, H., Ma, W., Wang, X. 2008. 'Rapid urbanization and implications for flood risk management in Hinterland of the Pearl River Delta, China: the Foshan study' *Sensors*, 8(4) p. 2234 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3673415/

Emergency responses

There seems to be no ‘official’ GBA/regional emergency response coordinated mechanism to the effects of climate-related natural disasters. Based on the response to typhoon Hato[64] in August 2017 which severely affected Macau’s infrastructure and when the People’s Liberation Army (PLA) garrison stationed there was called to help, it is doubtful that there is a coordinated regional mechanism among the three jurisdictions of Hong Kong, Guangdong and Macau. Nevertheless, during typhoon Mangkhut[65] affecting the area on 16 Sept 2018 a joint meeting was held by Hong Kong, Macau and Guangdong authorities to discuss how the region may be affected and respond. As recently as 11 March 2019, another joint meeting of the meteorological services of Guangdong, Hong Kong and Macao took place with discussions including strategies to cope with extreme weather that is becoming more frequent under the effects of climate change.[66]

Also, one can refer to several HKSAR guidelines and plans collated by the HKSAR Security Bureau to gauge regional preparedness. These are (a) the *HKSAR Emergency Monitoring and Support Centre (SB)* and the three-tier *Emergency Response System*; (b) the *Simple Guidelines in the Event of Major Mishaps* which are published in Chinese and English and cover tropical cyclones (T1-10), storm surges, rainstorm (yellow, red, black), thunderstorm, flooding, landslip, strong monsoon, hill fires (yellow, red), earthquake, tsunami, and nuclear emergency; and the (c) the *Contingency Plan for Natural Disasters* of the Emergency Support Unit of the Security Bureau. Chapter 5 of this plan includes warnings and action to be taken in case of floods.[67]

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[64] Hong Kong Observatory Typhoon Hato Data http://www.hko.gov.hk/informtc/hato17/hato.htm

[65] Hong Kong Observatory Typhoon Mangkhut Data https://www.hko.gov.hk/wxinfo/currwx/tc_pastpos_1826.htm

[66] Hong Kong Observatory, the 2019 Joint Hong Kong, Guangdong and Macao Meeting on Cooperation in Meteorological Observations http://www.weather.gov.hk/hkonews/A3/sidelight_a3_20190308.htm

[67] HKSAR Security Bureau. 2019. Emergency Response System http://www.sb.gov.hk/eng/emergency/ers/pdf/ERSc4.pdf

Guangdong Province also has a response system supported by the China National Commission for Disaster Reduction and the Ministry of Emergency Management[68], while Macau activates its civil protection and evacuation exercises via the Civil Protection Action Centre which was established in 2017 after typhoon Hato caused severed damaged to the city[69].

While, as its name indicates, emergency responses are essential, they are sort-term actions during critical events. They are not part of the long-term, climate adaptation policies that are more effective in mitigating the already-felt climate change impacts. Thus, which climate adaptation policies are in place to mitigate the effect of flooding in the region?

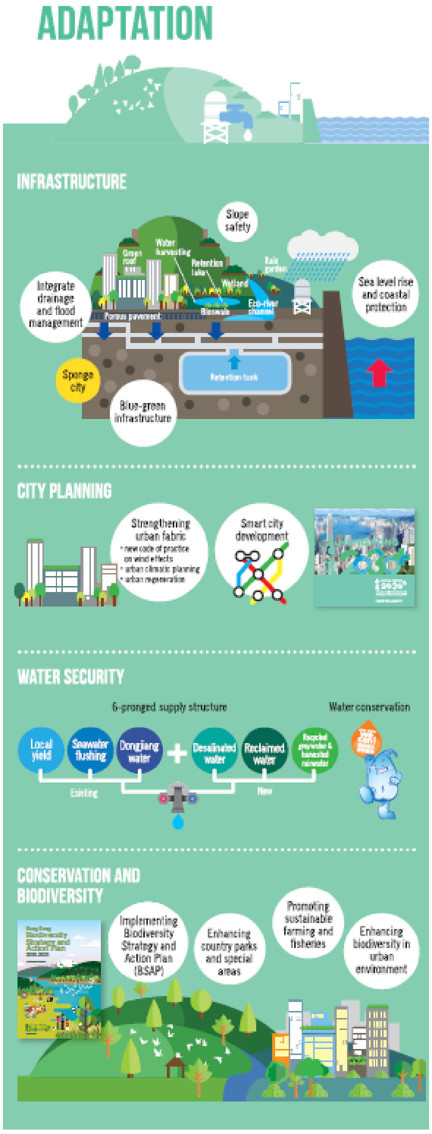
Climate adaptation policies

Figure 10, summarizes the four key areas on which policies got to be formulated to ensure climate adaptive capacity for an increasingly vulnerable and exposed GBA: *infrastructure, city planning, water security, conservation and biodiversity.* These are identified in the *Climate Action Plan 2030*+ published by Hong Kong.

[68] China National Commission for Disaster Reduction and the Ministry of Emergency Management http://english.gov.cn/state_council/ministries/2018/09/03/content_281476287314610.htm ; Macao Civil Protection Operations Centre https://macaunews.mo/government-sets-new-civil-protection-centre/

[69] Macau Post Daily. 2017. https://www.macaupostdaily.com/article2804.html

Figure 10. Climate Adaptation Key Areas[70]



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[70] Hong Kong Climate Action Plan 2010+, p. 8 https://www.enb.gov.hk/sites/default/files/pdf/ClimateActionPlanEng.pdf

With regards the other two jurisdictions of the GBA, Macau and Guangdong, after the damaged inflicted by typhoon Hato and as typhoon Mankhut approached, Macau announced in 2017 plans to reduce the impact of flooding in its Inner Harbour by beefing up its flood control infrastructure through the construction of a tidal barrier at Wanzai waterway in Zhuhai Prefecture, and an overall flood control system for the tidal basin covering Zhongshan, Zhuhai and Macao. Both projects have been approved by the relevant ministries and departments of the Central Government. [71] In 2017, the Macau government also announced that discussions were taking place with Guangdong Province authorities to put in place a cross-boundary flood prevention system.[72]

[71] Macau Business https://www.macaubusiness.com/macau-city-well-prepared-for-typhoon-mangkhut-legislators/

[72] Macau SAR Government Information Bureau (Gabinete de Comunicacao Social) https://www.gcs.gov.mo/showNews.php?PageLang=E&DataUcn=116506

By March 2018, Macau had taken short-term flood control measures for its Inner Harbour and had commissioned the Pearl River Hydraulic Research Institute[73] to study the possibility of installing a 2.13 kilometre, 3-meter high barrier that should be able to withstand tidal waves of up to 4.8 meters which, based on records, only occur on average once every 20 years. In addition, 13 fixed water pumps would be installed along the flood barrier to improve drainage and prevent backflow of seawater into the city's sewerage system. [74]

While through existing channels of cooperation, attempts are being made to put in place a regional climate adaptation policy with particular emphasis on flood prevention and control, this is not yet in place. **In the absence of a comprehensive and coordinated response and adaptation policy, sectors of the economy suffer from climatic changes as discussed below.**

3.5. Sectoral Vulnerability and Adaptation Assessment

As mentioned, due to the last 30-years of rapid industrialization, GBA today suffers the consequences of environmental degradation, including locally-induced GHG emissions and consequential climatic changes. These are compounded by its low-laying location. Figure 11 links to a map of the key infrastructure. While the map is helpful in geographically locating both existing and under construction infrastructure (expressways, railways, inter-city rail, 7 major airports, land control points, ports, cross-boundary ferry terminals, cruise terminals, high speed rail stations, and the 2 pilot free trade zones of Nanhai and Qianhai), it not only **omits the location of energy-related infrastructure such as thermal and nuclear power plants, transmission and distribution substations and networks, wind and solar farms and/or PV fields which is key to sustain the economic activity of the GBA but also the location of the main existing and planned industrial, manufacturing and residential towns.**

Figure 11. Interactive Map of Major Infrastructure in the Area (see link)[75]

The map provides no data either as to the vulnerability all these delta/coastal infrastructure may be subjected to due to sea level rise, typhoons and consequential high winds and storm surges, high rainfall incidence, heatwaves, etc. In fact, the key infrastructure that is highlighted as to matter for greater GBA integration are five mega projects described in Table 4. **The GBA project documents provide no information about climate-related vulnerability of these assets, although all of these projects must have been subjected to stringent risk assessments. Their individual websites provide information about environmental monitoring and assessment but this does include climate risk assessments.**

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[73] Pearl River Hydraulic Research Institute (in Chinese only) http://www.prwri.com.cn/
[74] Macau SAR Government Portal https://www.gov.mo/en/news/93131/
[75] Hong Kong Constitutional and Mainland Affairs Bureau HKSARG https://www.bayarea.gov.hk/en/connectivity/map.html

Table 4. Key GBA infrastructure[76]

Infra-structure	Characteristics	Commis-sioned	Asset Value	Vulnerability Assessment (SLR)
Hong Kong - Zhuhai-Macau Bridge (HZMB)	From HK port to Zhuhai and Macao 41.6 km; Bridge-cum-tunnel 75 mins Kwai Tsing to Zhuhai; 45 mins HKIA to Zhuhai; 3 hrs radius to Western PRD	2018 (completed)		The Hong Kong Highways Department provides information about the projects' environmental protection measures http://www.hzmbenpo.com/ A monthly environmental, monitoring and auditing (EM&A) report on air, noise, water, dolphin and site environmental inspections' findings is provided. This document includes a report on weather conditions (every 5 minutes) taken from the Tung Chung China State Office Rooftop. February 2019 report: http://www.enpo.com.hk/EMnA_Report/HKLR_HY201103/Monthly/201902/pdf/TOC.pdf
Express Rail Link (XRL (HK Section)	Express Rail Link; 4 mins to Futian; 23 mins to SZ North; 48 mins to GZ South	2018 (completed)	87 billion	The Hong Kong Mass Transit Railway Corporation (MTRC) provides a monthly EM&A report on ecological and vegetation impact of ongoing construction works, and on noise, landscape, water, air and waste. The report also includes meteorological data of Hong Kong including temperature, rainfall, visibility, wind direction and speed but not mean sea level or storm surges https://x.dantemanager.net/monitor/upload/EMA/2019/Feb.pdf
Boundary control point (BCP) at Liantang/Heung Yuen Wai (LT/HYW)	This is the seventh land boundary crossing between Hong Kong and Shenzhen. The crossing point is accessible by both passengers and vehicles; Daily capacity (17,850 cars; 30,000 passengers)	2018 (completed)		The Civil Engineering and Development Department (CEDD) announced the completion of the project on 14th March 2018 https://www.info.gov.hk/gia/general/201803/14/P2018031400446.htm?fontSize=1
Second Humen Bridge	Link Dongguan and Dongguan; 13 km	2019 (opens 2 April)		Dongguan Today http://www.dongguantoday.com/news/dongguan/201903/t20190327_8069313.shtml
SZ-Zhongshan Bridge	Sea crossing, sub-sea tunnel, artificial islands and underground interchange; 4 lanes (100 Km/h); SZ to Zhongshan 20 mins	2024 (ongoing)		China Economic Net http://en.ce.cn/Business/topnews/201903/26/t20190326_31742778.shtml

[76] Greater Bay Area Key Infrastructure https://www.bayarea.gov.hk/en/connectivity/key.html

The more frequent and expansive damage that the world has seen during the Summer of 2018 from extreme weather conditions linked to climate change should make any decision-maker vouching for investment and movement of goods and people to vulnerable areas think twice or prepare. Torrential downpours, massive landslides, and floods in areas that had already been assessed as being vulnerable will unfortunately recur. Hazard maps, adaptation infrastructure and emergency and evacuation measures have to be part and parcel of a project of the magnitude of the GBA that is home to more 68 million people.

As an example, Figure 12 illustrates the changes to an industrial park in Shenzhen after a massive landslide that occurred in 2015. More than 80 people lost their lives.

Figure 12. A before and after aerial photo of a massive landslide in a Shenzhen industrial park, December 2015[77]

The following assets and services may be affected if climate adaptation mitigating measures are not in place.

- **Trade** and distribution logistics assets and services (airport, ports, roads, warehousing, commercial centers). i.e. Nansha Deep Water Port
- **Manufacturing** assets and services: traditional light (electronics and electrical components and products, watches, toys, garments and textiles); traditional heavy (cement and steel); and innovative (smart phones, civil drones, jetpack, gene research, robotics, media platforms, etc in companies like Huawei, ZTE, Tencent, DJI Technology Co, Xenosky, Flypro, etc)[78]
- **R&D infrastructure** (universities, science parks, incubation labs, start-ups, etc), i.e. in Tianhe: the Guangzhou Economic and Technological Development Zone, the Guangzhou Convention Center, the University Town, new International Airport
- **Energy** assets and services (oil, gas, nuclear, electricity G,T&D)
- Water; Agriculture, Forestry & Biodiversity; Public health
- **Financial services** (banks, insurance companies, stock brokerage, accountancy, investment funds, etc)
- **Professional services** (architectural, engineering, auditing, medical, legal)

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[77] South China Morning Post, 20 Dec 2015 https://www.scmp.com/topics/shenzhen-landslide
[78] Phys Org. China's High-tech future emerges in factory town Shenzhenhttps://phys.org/news/2016-05-china-high-tech-future-emerges-factory.html

4. Methods: A Transformative Approach to Transformation

Reflecting on the unsustainable patterns that may have contributed to recent disruptive events which are seriously affecting people and assets (i.e. drought and the Arab Spring revolutions; Katrina and Sandy hurricanes in the US; Hiroshima floods; Kansai airport floods and Hokkaido earthquake and landslides in 2018, etc) and in the hope that these unsustainable patterns will not be replicated in urban projects of the future, the German Advisory Council of Global Change (WBGU) is proposing a new 'global social contract for a low-carbon and sustainable global economic system'[79]. WBGU argues that:

'The fossil-nuclear metabolism' of the industrialized society has no future. The longer we cling to it, the higher the price will be for future generations. However, there are alternatives which would at least give all people access to the chance of a good life within the boundaries of the natural environment. Without a global agreement to actually dare to experiment with these alternatives, ***we will not manage to find our way out of the crisis of late modernity****. So nothing less than a new social contract must be agreed to. Science will play a decisive, although subservient, role here. Ultimately, sustainability is a question of imagination'* [80]

What this social contract implies is the need for a 'great transformation' [81] which would require individuals and institutions to resolve problems by taking a holistic and policy coordinated approach to governance so as to achieve a 'climate – compatible and sustainable social and economic order'. [82]

How will this new social contract that is proving efficient elsewhere, for example in the Tokyo Bay and the San Francisco Bay Areas[83], may be enabled in the Greater Bay Area of China project? What is the role of technological innovation in advancing this social contract and what are the drivers and barriers for technological innovation in making resilient flood-prone coastal cities?

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[79] German Advisory Council on Global Change (WBGU) World in Transition: A Social Contract for Sustainability https://www.wbgu.de/en/flagship-reports/fr-2011-a-social-contract/
[80] Ibid. p. 25
[81] Heinrich Böll Stiftung, p. 1 https://www.boell.de/sites/default/files/uploads/2015/04/transformation_research_juli2015.pdf
[82] Ibid. p. 2
[83] San Francisco Bay Area https://www.spur.org/publications/spur-report/2018-08-22/four-future-scenarios-san-francisco-bay-area

III. Technological Innovation for Climate Adaptation and Resilience

White et al. [84] argue that **flood resistance (FRe) and resilience technologies** have the potential to limit the damage caused by flooding. While **resistance technologies** generally aim to keep water out of infrastructure/buildings, **resilient measures** may allow ingress but create the conditions for a quicker recovery of individuals, communities and buildings. However, despite their potential contribution to **flood risk management (FRM)**[85] their use remains uncommon. These conclusions are arrived at by climate resilience strategists based on a pan-European research of local communities at risk and their representatives and of stakeholders working at a more strategic scale **to explore the barriers to use technology and describe the co-production of best practice.** They interrogate the issues in terms of **level of awareness, degree of acceptance and the integration into decision-making.** They find that even where awareness is high, there is a reluctance to use flood resistance and resilient technologies due to **comparability, costs, installation, performance and maintenance issues.** Their research also reveals that FRM policy and practice has struggled to incorporate the flood resistance approach and that many individuals, regional and local authorities that are at risk are reluctant to take responsibility and protect infrastructure/properties in this way.[86] Table 6 presents a number of available technologies for flood control and their corresponding adaptation objective.

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[84] White, I., A. Connelly, S. Garvin, N. Lawson and P. O'Hare. 2016. Flood resilience technology in Europe: identifying barriers and co-producing best practice. *Journal of flood risk management,* in CIWEN Consultation Response. 2016 to the National (UK) Flood Resilience Review. https://www.ciwem.org/assets/pdf/assets/uploads/CIWEM_response_National_flood_resilience_review.pdf

[85] The EU Flood Risk Management is the generally accepted concept and process: prevention, protection, preparedness, emergency response and recovery (lessons learned) http://ec.europa.eu/environment/water/flood_risk/flood_risk.htm

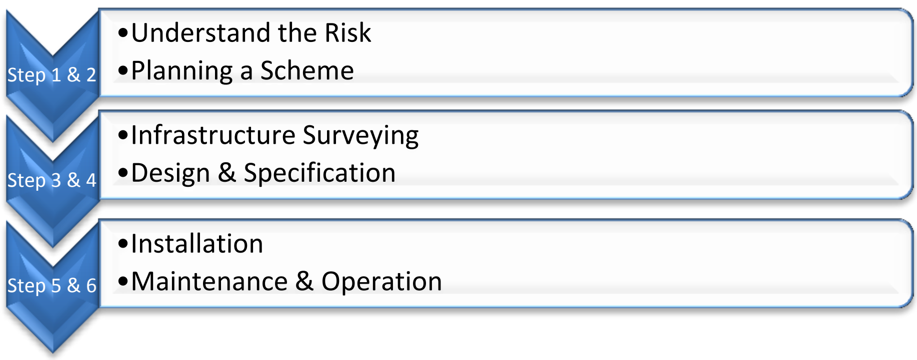
[86] Ibid.

Table 6. Adaptation Technologies Relevant to Asia's Coastal & Water Resources and Disaster Risk Management[87]

Technology	Description	Adaptation Objective
Structural Barriers	Levees, dikes, sea walls, tide gates, storm surge barriers	Coastal protection
Beach nourishment and dune construction	Artificial addition of sediment to a beach area with sediment deficit; shaping sediments into dunes	Coastal protection
Surface water storage	Reservoirs, cisterns, tanks and ponds to collect and store water for future use	Water security
Structural barriers to flood-ing	Dams, dikes, locks and levees	Inland flood protection
Early warning systems	Forecast and warn of near-term weather-related extreme events such as heat waves, flooding, coastal storms, fires, and mudslides	Reduce disaster-related risk and lower residual risk

In the following section, a preliminary discussion on the key issues that emerge at the stage of designing, testing and learning from innovation is made. The discussion uses the good practices guidance – the 'Six Steps approach' – co-produced with UK stakeholders to facilitate the wider contribution of FRe to FRM.[88] The six steps are represented in Figure 13.

Figure 13. Six Steps to Flood Resilience[89]



[87] The IoT Marketplace Smart Flood Prevention Products https://www.the-iot-marketplace.com/solutions/smart-flood-prevention
[88] Six Steps to Flood Resilience: Guidance for local authorities and professionals. Version 2, August 2013 https://www.bre.co.uk/filelibrary/pdf/projects/flooding/Six-Steps-Professional-web-Aug2013.pdf
[89] Ibid.

1. Designing, Testing and Learning from Innovation

While the *Outline Development Plan for the Greater Bay Area* makes a broad mention of flood prevention measures such as: strengthening seawalls and riverbanks, managing rivers and lakes, enhancing drainage systems and water holding capacity, solving the problem of urban flooding, reinforcing reservoirs and sluices, monitoring water resources, developing a system for monitoring and warning, and increasing collaborative prevention, control and emergency response,[90] no reference is made about a GBA climate action plan nor about the role of technological innovation in flood prevention in times of climate change. This, despite the fact that the Plan also mentions using the smart municipal management and smart communities approach to governing the GBA by 'developing information infrastructure facilities, including a comprehensive sensor network'.[91] The connection between climate change, flood prevention and technological innovation seems absent.

Following White at al.[92] and to overcome the reluctance in using flood resistance and resilient technologies, a review of six steps that may help bridge the gap of knowledge for climate resilience in the GBA is made. This includes the tasks to be undertaken at each step and the anticipated outcomes (Table 7).

[90] Outline Development Plan for the Guangdong, Hong Kong Macau Greater Bay Area (courtesy English translation), p. 25
[91] Ibid. p. 23.
[92] White et al. 2016. Flood resilience technology in Europe: identifying barriers and co-producing best practice. *Journal of flood risk management,* in CIWEN Consultation Response. 2016 to the National (UK) Flood Resilience Review. https://www.ciwem.org/assets/pdf/assets/uploads/CIWEM_response_National_flood_resilience_review.pdf

Table 7. Climate Resilience Steps to Climate Resilience to Flooding[93]

Steps	Tasks	Outcomes
1. Understand Flood Risk	* Survey * Identify sources & routes * Use available flooding data : flood risk, topography, surface water, ground water, historic, risk assessment, maps * Inform about technological products' specifications, installation, costs, qualification for government subsidies & end-users' manuals * Inform about the effects of installing technologies in one infrastructure/neighborhood on infrastructures nearby	A comprehensive flood risk mitigation survey
2. Planning a Flood Scheme	* Check if existing flood plan is suitable to integrate FRe technologies * Gauge pros and cons of automatic versus/and/or manual measures and their deployability * Gauge stakeholders' capacity to handle manual measures in a flood * Do a cost benefit analysis (CBA) of deploying technical and/or manual measures accounting for climate change in this CBA * Engage stakeholders to ascertain manual and/or technical measures are acceptable * Identify other locality schemes that can work in tandem with flood plans * Identify 'champions' that can lead and maintain momentum with the plan	A clear and workable plan based on science, technology, finance and stakeholders' consensus
3. Survey Infrastructure to be protected	* This includes: vulnerable points, apertures, masonry, drains and pipes, sewage backflow (if any), users' ability to deploy, store and maintain products * Check on the visual aesthetics of the new measures	Full site survey
4. Design & specification of new technologies (FRes)	* Communicate results of the property survey to the designer of the technology * If a different supplier is used for the installation of the technology, communicate with him/her the results of the property survey too * Communicate performance limitations of products to ends-users	Designers & installers are engaged and a schedule is set for installations to commence
5. Technologies' Installation	* Timing, supervision, additional support and final inspection of the installation are agreed upon * An information package is provided to end users * A post-installation test is carried out to ascertain reduced risk to infrastructure/property	FRe technologies installed, visual data and post-installation survey provided
6. Maintenance & Operation	* Provide end-users with operational, storage and maintenance instructions & costs * Do a user demonstration * Revise emergency plans taking account of new installed technologies	FRe maintenance and operations communicated

[93] Adopted from Ibid. pp. 9-32

While these steps can be used in designing, testing and learning for technical innovation for flood control in the GBA, **drivers and barriers to the uptake of technology got to be identified.**

2. Innovation Drivers & Barriers for Climate Resilience

In a comprehensive overview by Grubb[94] of issues and options for the uptake of technological innovation in climate change policy (applied to the energy sector), he posits that the process of innovation is not linear and that there are drivers and barriers along the way that got to be identified. These are summarized in Table 8.

Table 8. Drivers & Barriers in the Uptake of Technological Innovation for Climate Resilience[95]

Drivers	Barriers
Communicate the co-benefits: technological innovation stimulates policy advancements in non-climate resilience related areas. For example, by creating jobs, growing the economy, etc	**Uncertainty:** about long-term pay offs of innovative technologies.
Set innovation-friendly government policy: in support of public and private investment in R&D	**Level of cooperation among involved parties:** different players may have different incentives to be involved. This applies both globally and locally.
Rely on the market pull: scale of investment fosters technological change	**Perceived or real gap** between funded R&D and commercially viable applications.
Steer the technological push: the level of public and private initiative fosters innovation	**Ease or difficulty of entry:** established companies and stakeholders may hamper new comers from coming in.
Be prepared for failure: gauge how much you can bear!	

While identifying the drivers and barriers in the uptake of technology, these got to be put in the context of the GBA to ascertain the opportunities and risks that such technology may bring to the area and what recommendations may be provided.

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[94] Grubb, M. 2005. 'Technology Innovation and Climate Change Policy: An Overview of Issues and Options' *Keio Economic Studies*, 41(2), pp. 103-132.
[95] Adapted from Ibid.

IV. Conclusions & Recommendations: A Resilient & Prosperous GBA

This analysis finds that given the ambitious plans for the GBA to contribute to the economic development of China, existing and projected vulnerabilities to climate hazards and their potential impact on the built environment and physical infrastructure may not only hamper GBA development plans but also put its businesses and citizens at great risk. Technological innovation diminishes this vulnerability but a process of designing, testing and learning got to be put in place as well as the recognition of drivers and barriers to its uptake must be identified.

The potential climate vulnerabilities to different sectors of the economy in the GBA are presented in Table 9. While it is too soon to say what the opportunities of the uptaking of technological innovation are before it has actually been uptaken, risks such as comparability, costs, installation, performance and maintenance identified by White et al. as well as those created by implementing technological innovation in an environment with entrenched traditions of protectionism, overdependence on governments (at least in Guangdong cities), intercity rivalry, overspecialization and the general decline in competiveness, are possibly good candidates.

Table 9. Potential Climate Change Vulnerabilities of the GBA[96]

Biodiversity	Built Environment	Business & Industry	Energy Supply
*Stress to terrestrial and freshwater ecosystems due to increase surface temperature and extreme weather. *Loss of intertidal habitats such as coral reefs and mangroves due to sea level rise. *Increased erosion and landscape degradation and change in species distribution and migration patterns.	*Damage to building foundations. *Damage to utility cables, pipes and assets. *Increase risk of leakage by rain penetration and of flooding and landslides due to strong winds, and storm surges. *Collapsed urban trees and damage to property due to strong winds.	*Higher maintenance and insurance costs due to extreme weather-related damage. *Higher cost of staff training to manage extreme-weather events. *	*Damage to electricity generation, transmission and distribution systems. *Higher energy demand to meet extreme temperatures and consequential supply spikes and interruptions.
Financial Services	**Food Resources**	**Human Health**	**Water Resources**
*Direct and indirect risk related to communications and computer system failure due to extreme weather. *Increase costs as risk profiles of individuals and business change to cope with climatic changes.	*Lower availability of local food output as climatic changes affect harvests. *	*Increase in heat-stress related illness such as cardiovascular and respiratory diseases. *Increase in accidents due to extreme weather related events. *Unpredictable changes in transmission patterns of infectious diseases.	*Drought and rise in demand of water due to higher temperatures. *Inability of infrastructure to cope with water excess in cases of higher rainfall.

[96] Adapted from the Hong Kong Climate Action Plan 2030+, p. 86 https://www.enb.gov.hk/sites/default/files/pdf/ClimateActionPlanEng.pdf

Thus, we recommend key stakeholders such as political, government, business, investment and civil society leaders to collaborate in making the GBA a climate resilient place and do this by resolving climate-related problems in a policy coordinated manner so as to achieve a climate-compatible, sustainable and transformed social and economic order.

Table 10. Key recommendations

Stakeholders	Key Recommendation
Political and Government Leaders	▪ Bring society together ▪ Set Adaptation Targets ▪ Formulate Adaptation Policies
Business Leaders	▪ Set science-based (not profit-based only) adaptation targets ▪ Make resources available for R&D and for application ▪ Encourage Innovation
Investment Leaders	▪ Deploy resources to expand adaptation technology ▪ Invest in sustainable companies, divest in unsustainable ones
Civil Society Leaders	▪ Hold governments and business committed and accountable ▪ Enable behavioral change

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