ICZM & the Application of Geosciences in the Chinese Coastal Zone

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Summary

In recent decades, the China's coastal zone is being faced with large-scale urbanisation, industrial and harbour development. The increasing coastal development, land use and marine pollution, conflicts between coastal and offshore activities led to the introduction of Integrated Coastal Zone Management (ICZM) in China at the beginning of 1990s. Geoscientific research plays an important role in the present planning of large-scale buildings, infrastructures and reclamation, the creation of coastal Eco-Cities, and in future adaptation to the impacts of climate change. ICZM is important and has been practiced. Examples of integrated development in three deltaic areas demonstrate the importance of geosciences, contributing to the ICZM process in China.

1 Introduction

China's coastline has a length of 18,400 km. If the coastal zone is defined between 10 kilometre inland and the – 10 m contour line offshore, it occupies 13% of the total territory of the country, and accommodate around 40% of its population. Of the gross domestic product (GDP) of China, 60% is produced in the coastal zone, which makes it the most important economic zone of China. In addition, China's coastal zone also acts as the door to the outside world.

China's government and the public value China's coast greatly and for that reason it has launched several projects involving multidisciplinary investigation of coastal processes and coastal management. In addition, there have been a number of thematic investigations in some key areas and two nationwide integrated surveys. However, due to the geological complexity, impacts of climate change and the sometimes competing activities in and around the coastal zone, major challenges for geoscientists within an ICZM framework lie ahead.

A preliminary vulnerability assessment to sea level rise, revealed that the low lying coastal areas, particularly the deltas of the Old Yellow River, Yangtze Delta and the Pearl River (encompassing about 35,000 km^2), are most vulnerable areas. Considerable costs, dealing with additional reinforcement of dikes to avoid impacts of a 1 m sea level rise, were also preliminary estimated (Du Bilan, 1993). Later studies on sea level rise and its impacts on the Chinese coastal zone confirmed the potential critical effects.

2 Geological background

China's coast extends from Hainan Island in the far south to Liaodong Bay in the north. China's coastal zone crosses 22 degrees of latitude ranging from the tropics in the very south around Hainan Island, sub-tropics in the area near the Yangtze River and temperate regions to the north. Precipitation decreases from south to north - from over 2000 mm per year in the southern provinces to 500 to 800 mm per year in the provinces around Bohai Bay.

The stability of a low-lying sedimentary coast depends upon the balance of the sediment input supplied by the rivers and the coastal processes exerting pressure on the shoreline. The majority of the largest rivers of China discharge along the eastern coastline. The total drainage area of these rivers comprises 45% of the total territory of China and water discharge is up to 70% of the total of all rivers of China. Among these rivers, from north to south the major rivers are Liaohe River, Haihe River, Yellow River, Huaihe River, Yangtze River, Qiantang River, Minjiang River and Pearl River . Water discharge [10^9 m^3/yr] and sediment load data [10^6 ton/yr] of these major rivers are presented in Table 1. The total long-term water discharge approximates to 1270 x 10^9 m^3/yr and in total, these rivers supply sediments on a long-term average of 1270 x 10^6 ton/yr (Liu Cheng et al., 2007). This total sediment discharge decreased considerably to 477 x 10 ^{6} ton/y during the decade 1997 – 2006, while the total water discharge remained more or less the same. The Yellow River however lost two thirds of it water discharge and sediment load during the last decade. This large river nevertheless transports a considerable but reduced amount of sediments to the sea with a relative low water discharge.

Table 1: Water discharge and sediment load data of China's major rivers (Liu Cheng et al., 2007)

River (control station)	Drainage basin (10^3km^2)	Data time ranges	Water discharge (10^9m^3)		Sediment discharge (10^6t)	
			Long-term average	1997-2006 Average	Long-term average	1997-2006 average
Liaohe R. (Tieling)	120	1954-2006	3.0	1.6	12.2	2.6
Yellow R. (Lijin)	752	1952-2006	31.1	11.2	766.5	163.6
Huaihe R. (Bengbu)	121	1950-2006	26.9	24.0	9.3	4.8
Yangtze R. (Datong)	1705	1950-2006	899.6	917.8	407.9	256.9
Qiantang R.(Lanxi)	18	1977-2006	16.5	16.6	1.9	1.6
Minjiang (Zhuqi)	54	1950-2006	53.8	58.1	6.0	2.8
PearlR.(Boluo, Gaoyao)	377	1964-2006	242.1	244.8	69.7	45.2

Since the Yellow River shifted its channel from the south to its current location in 1855 (CCC II-2-2), the delta has grown by 20 km^2 per year.
The Yangtze River delta has expanded since the Late Qing Dynasty at a rate of 9 km^2 per year. Since 1970 there has been a reduction in water discharge and sediment load due to the decrease in precipitation and increase in human activities in the upper reaches of the rivers. Because of the reduced sediment load carried by the rivers, the sandy and muddy coasts of Bohai and Yellow Seas are increasingly eroding.

3. Coastal zone management`

With the increasing development and land used along the coastal zone in China, conflicts between coastal and offshore sea-related activities and increasing marine pollution led to the introduction of ICZM into China at the beginning of 1990s. The need to strengthen (marine) legislation and formulation of regulations to effectively coordinate and manage the ocean resources and the coastal zone of China was presented by Zhang Guochen (SOA) in 1993.
The State Oceanic Administration (SOA) of China is the Central Government authority for coastal and offshore management. Provincial and municipal marine management authorities are in charge of the local coastal management based on national and local laws and regulations. ICZM concepts and methods are taught in the universities and studied in many research institutions in China.

Chinese "Regulation of Sea Uses" for regulating the coastal and offshore uses came into force in 1993. At the same time the National Coastal and Offshore Planning Framework was initiated, with concepts and theories of integrated coastal zone management fully introduced and practiced in the planning process. After 1998, local government started province-based or municipal-based coastal planning according to the national general planning framework and local development demands. In 2000 and 2001, the "Law of Marine Environment" and "Law of Sea Uses and Management" came into being with the enforcement of coastal and offshore management.
In the meantime, Chinese central government and local authorities cooperated with international organisations on ICZM issues, for instance, International Oceanographic Commission (IOC) have provided ICZM training for Chinese coastal and marine researchers and managers. Partnerships in Environmental Management for the Seas of East Asia (PEMSEA) sponsored an ICZM demonstration project in Xiamen city at the southeast coast of China in the past decade, to introduce the new concept of ICZM and transfer the technology associated with its implementation. An ICZM framework for Shanghai was introduced (Shi et al.2001). ICZM is also well practiced in other major coastal cities, such as Qingdao, Dongying, Dalian and major economic zones, such as Bohai Bay area, where coastal developments are ongoing, and marine and high quality coastal habitats are at risk (Liu Xuehai, 2010).

Role of geoscientists

The role of geoscientists is very important within China's ICZM. During 1980s and early 1990s, a series of coastal zone and islands survey projects were conducted along the Chinese coast. Important geological information including topography, geomorphology, offshore bathymetry, sedimentology, stratigraphy, groundwater, mineral resources, coastal stability and potential geo-hazards, was collected. This information has been taken into account at the stage of coastal planning, especially for large scale, geological related coastal activities, such as the planning of harbours, across-bay bridges, (nuclear) power plants and other major coastal engineering projects.
With the high intensive coastal development, environmental challenges occur. These include serious pollution, coastal erosion, coastal wetland loss, groundwater shortage, subsidence due to groundwater over-extraction and increased risk of flooding due to sea-level rise. Environmental geology survey projects carried out along the Chinese coast aim to satisfy the information demand of ICZM.
Bringing all the different types of valuable information together in a coherent way, uses the application of Geographic Information Systems (GIS, see also CCC II-2-2 and III-3-2-1). The China Geological Survey (CGS) started the Coastal Environmental Geological Survey Programme in order to provide more detailed and updated geological information for coastal planning, management and protection. According to the Chinese "Law of Sea Uses and Management", for each single coastal project an Environmental Impact Assessment (EIA) has to be carried out. One of the key factors within the EIA is to undertake a geological environment assessment.

4. Three examples of the role of geosciences in development

In the text below the developments in the economic areas of Bohai Bay, Shanghai including the Yangtze River delta and the Pearl River delta and the south eastern provinces will be discussed.

Chinese Coastal Area.
(Source: Geological Survey of China)

*Figure 1: **Map of Chinese Coastal Zone,** the red rectangles show the location of three coastal development areas:*

- *Caofeidian Bohai Bay,*
- *Shanghai and Yangtze River Delta and*
- *Pearl River Delta.*

4.1 Caofeidian Bohai Bay

The Caofeidian Island is located along the Bohai Bay, and is suitable for large-scale deepwater ports and industries. According to a bathymetrical survey undertaken by Qingdao Institute of Marine Geology (Research Report of Digital Coastal and Offshore of Nanpu-Jidong Oil Field, 2005), the water depth at 500 meters offshore reaches 25 meters, while the trough in front of the island, the lowest point of the Bohai Sea, is 36 meters deep. These water depths allow the construction of terminals for 300,000 ton ships without the need to dredge a new shipping channel. In order to create space for a deep water port, large-scale land reclamation has to be carried out: an area of 310 km^2 will be converted into land, with an average infill depth of about 5 m, which means that more than 1.5 billion m^3 sand will be dredged.

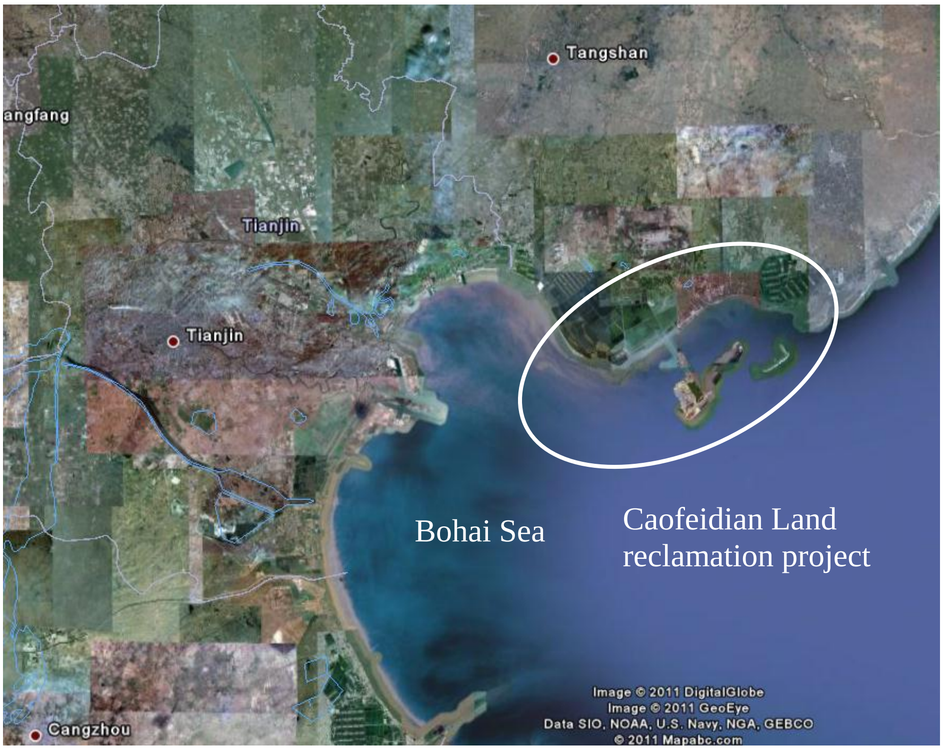

*Figure 2: **Location map of Caofeidian project area** – 310 km^2 land reclamation. (photo: Google-Earth: Image©2011 Digital Globe, Image©2011 GeoEye Data SIO, NOAA, U.S.Navy, NGA, GEBCO, ©2011 Mapabc.com)*

To accelerate the overall development of Caofeidian, by

2003 the construction of infrastructure facilities began. The 18.74 km long Tongdao Sea Bridge Highway was opened in September 2004. The Qinlin Road, electricity supply, and communication projects became operational by the end of 2005. Other projects, such as a water supply project, the port railway, and a project for an iron and steel plant, were completed by the end of 2008.

Tectonic stability

Meanwhile geo-biological and geo-environmental problems were taken in consideration during such a large-scale land reclamation project.

One of the major concerns is the tectonic stability related to settling pressures in this reclamation area. The deep water – the so-called trough - and the nearby relative steep slopes, poses a real challenge. Caofeidian is also close to the Tanlu Earthquake zone. The Tangshan Earthquake (7.8 degrees at Richter's Scale) happened on the 28th of July, 1976 killing more than 250,000 persons. The earthquake centre was only 60 km from Caofeidian. The concerns of the Caofeidian reclamation project are the earthquake risks for the newly built infrastructure and for the land reclamation, especially the area close to the deep-water channel, which might be susceptible to submarine slope slides. A series of survey and monitoring projects had been set up for earthquake risk assessment

The subsidence rate and the stability of the deep water channel slope are monitored frequently.

Eco-City Caofeidian

According to the national plan, the overall development and construction of Caofeidian will be carried out in two phases, the industrial harbour phase to receive up to 300,000 ton vessels and the construction of the Caofeidian Eco-city (see CCC II-2-4), which will require large amounts of drinking and industrial water. Large-scale water abstraction will affect the wetland ecosystem in Tanghai County, where biodiversity will also suffer from industry and shipping activities.

By the use of hydrodynamic numerical models of Bohai Sea, researchers studied the change of hydrodynamic conditions at the different stages of the land reclamation activities. The comparison shows that the impact of the construction will cause the current velocity to increase near the shoreline causing seabed erosion.

Other geo-environmental problems in the near future include the seawater intrusion drastically affecting rice cultures, land subsidence, and shoreline instability exacerbated by the anticipated impacts of future climate change.

To compensate for the loss of wetlands, artificial wetlands will be constructed, which will also be designed to store two million m^3 fresh water.

In order to build a safe modern Eco-City of Caofeidian in the near future, a comprehensive analysis of the coastal environment and geological processes along with the socio-economic processes in the Caofeidian area is necessary. Such an integrated approach will also increase the ability for adaptation to future climate change and in the long term to be better prepared for geological disasters such as earthquakes and tsunamis.

For more information on the rapid Caofeidian development, see the CIZAC website.

Figure 3: ***Digital Elevation Model of the terrestrial and sub-marine part of the Caofeidian project area:*** *in green the intertidal areas dissected by tidal channels. The 18.74 km long Tongdao Sea Bridge Highway was opened in September 2004. The large scale land reclamation (310 km2) is projected on the intertidal areas SW of the Sea Bridge Highway, will be step wise executed and finished in 2020. (source: Qingdao Institute of Marine Geology)*

4.2 Shanghai coastal zone development

Yangtze River Delta area is one of the most intensely developing coastal regions in China. It has the highest population density, a rapid urbanisation, and large-scale coastal infrastructure developments (see Figure 4). However, present day impacts and future changes will affect coastal resources, living conditions and the environment.

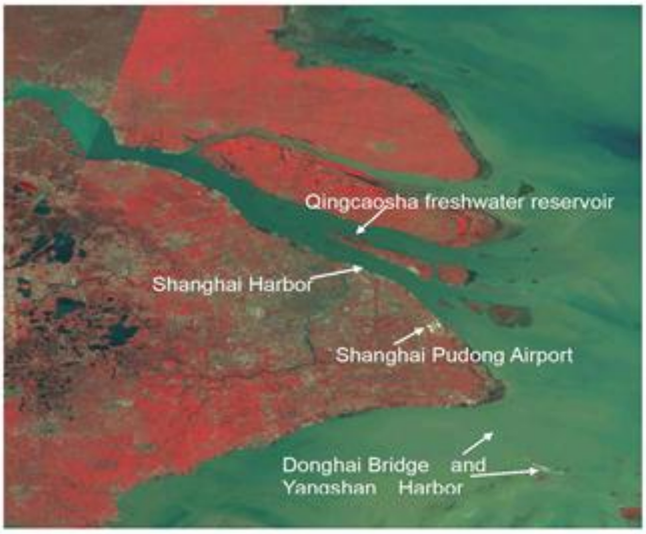

Figure 4: ***The location of the large scale coastal projects in the framework of the Shanghai*** *coastal zone development (photo: Jun FU & Ping YIN): including the 32.5 km long Donghai Cross-sea Bridge. (photo: Zhang 2008)*

Threats

The Yangtze River Delta suffers from serious subsidence as a combined result of sediment compaction and over-extraction of groundwater. Between 1921 and 1965, in the Shanghai central area subsidence reached 1.75 m = 4 m/century. The situation in Shanghai is currently under control by regulating the use of ground water. The subsidence rate of Yangtze River Delta urban area, however is on average more than 5 mm/year, and in some new, developing urban zones even higher. These rates of subsidence are of serious concern, realising that the average elevation of the vast Yangtze River Delta area is between 3-5 m above the present mean sea level.

Also global warming and sea-level rise may threaten the coastal zone and can cause enormous damage due to increasing frequency and strength of storm surges and floods. The coastal storm-surge protection dike along the river bank had to be raised from 4.7 m to 5.85 m in the last three decades. Increased sea level rise will also affect the salt water intrusion into the fresh water aquifers in the coastal zone and in the rivers.

Seawater intrusion into the Yangtze River Delta is also influenced by the decreasing river water discharge due to upstream damming and the increasing demand for water in the lower delta. Seawater intrudes along the Yangtze River, which resulted in a serious event in 2006, when it reached up to 170 km upstream from the coast.

Effects of damming

Large scale damming of the upstream Yangtze River and siltation behind those dams led to vast coastal erosion as a result of decreased sediment discharge. New approaches such as sediment agitation and special low-dam sediment discharge devices are part of the Three Gorges Dam construction. Sediment discharge (in 10^6 ton/y, Figure 5) from the Yangtze River to the Yangtze River Delta decreased by 40% since 1950s, resulting in increased coastal erosion. Whilst under natural condition most deltas are growing about 40% of the coastline in Yellow River Delta area is directly threatened by erosion. The construction of the Three Gorges Dam began in 1994, and the dam was closed for storing water at the beginning of 2003.

After 1998, there was a tendency for lower sediment discharge and by 2005 only about 200 million ton/y , was released due to retained sediments during the filling of the reservoir. The beneficial effects of special dam adaptations, which focused on the continuation of the sediment transport through the dam, may become clearer in the future.

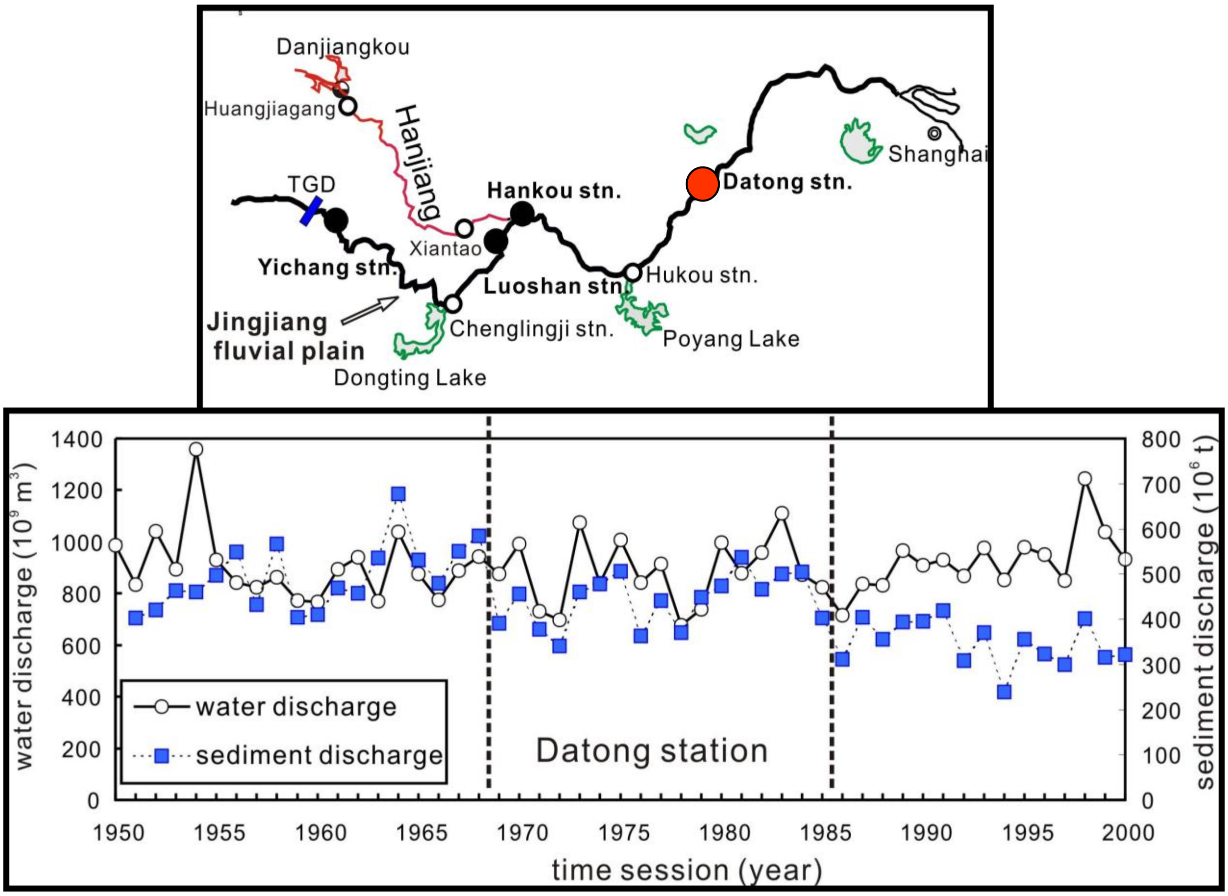

Figure 5: ***Yangtze River sediment and water discharge variation*** *from 1950 to 2005, records from Datong station, located down stream of the Three Gorges Dam (TGD) and 600km upstream from the Yangtze River Delta.* (*source: Yang et al., 2006*)

Need for geological information in urban development

Shanghai with more than 18 million inhabitants is the largest coastal city of China. The rapid urbanisation of Yangtze River Delta demands land and fresh water. A sustainable development of Shanghai needs space and resources from both the coast and the offshore zone. As well as the clear need for geological information with regard to its tectonic setting and a detailed assessment of the stability and dynamics of the coast and it's subsurface, additional information on water resources and quality is required.

Shanghai is looking for safer fresh water supplies and in 2007 the construction of the Qingcaosha fresh water reservoir, began on the Changxing Island in the Yangtze River mouth with an area of 70 km^2, and an effective volume of 435 million m^3 (see figure 4). The daily water demand of Shanghai County is about 7 million m^3. The fresh water reservoirs will be mainly fed with rainwater and with river water only during periods when there is a large river flow.

Information and data on water quality, coastal stability, and underground stability (for construction) are very important for the development of the coast. Construction of a cross-sea bridge (Donghai Bridge, Figure 4) required detailed geoscientific information of the tectonic stability, sedimentary processes acting on the seabed and the composition of the subsurface.
Given the on-going reclamation projects in and around the coastal zone for harbours and airports there will be a continuous need for geo-scientific support on long- and cross-shore sediment transport processes, subsidence and storm surge risk assessments.

Figure 6: ***Donghai Cross-sea Bridge (in the horizon) and Yangshan Harbour*** *The project started in June of 2002 with the construction of the 32.5 km long Donghai Cross-sea Bridge connecting Shanghai and Yangshan Harbour; the opening of Yangshan Harbour: December, 2005; the Phase-3 of Yangshan Harbour finished in December 2008. The Yangshan Harbour key reached a length of 5600m. The whole project will be finished in 2020.*
(source: http://en.wikipedia.org/wiki/File:Yangshan_Deepwater_Port.jpg)

The successful constructions of the Donghai cross-bridge, Yangshan (Figure 6) and Shanghai harbours and the Pu Doing Airport showed that a fundamental understanding of the geology and dynamic coastal processes are essential and can take into account the natural environment.

4.3. Developments of Pearl River Delta

The Pearl River Delta zone covers nine prefectures in the province of Guangdong (Figure 8) and had a population of approximately 60 million people in 2008. Since the late 1970s, the Pearl River Delta has become one of the leading economic regions and a major manufacturing centre of China. It is one of the world's workshop producing products such as electronic goods (watches and clocks), toys, garments and textiles, plastic products, and a range of other goods.

New transport links between Hong Kong, Macau and Zhuhai in the Pearl River Delta are expected to open up new areas for development and facilitate trade within the region. The proposed 29-kilometre Hong Kong-Zhuhai-Macau Bridge will be among the longest in the world.

Environmental problems
The industrial activities caused the delta to become severely polluted. The sewage and industrial waste treatment facilities is unable to keep pace with the growth in population and industry. Much of the area is frequently covered with brown smog, increasing the pollution levels in the delta.

At the same time, practically no natural coastal landscape remains, due to human interventions. Most of the delta plain is poorly protected, being situated below local high tide and storm-surge levels. The delta region is thus exposed to natural disasters such as typhoon-driven storm surges and ground subsidence caused by local sediment compaction and regional tectonics. These effects are compounded by the threat of accelerated relative sea-level rise estimated to reach 0.5 m within the next 50 years. Without massive protection works this would lead to the inundation of 95% of the delta region, and could include the destruction of entire cities such as Guangzhou.

The effects of human interventions in the Pearl River Delta region have the same significance as those associated with geological processes. This important aspect has to be taken into account when studying the recent evolution of the delta, especially when seeking sustainable solutions for the economic development of the region.

Figure 7: ***Location map of the mouth of the Pearl River and its surroundings*** *with Hong Kong, Macau and Zhuhai.*
(source: © Croquant / Wikimedia Commons / CC-BY-SA-3.0 & GFDL)

5. The role of geo-science in the coastal projects

Qingdao Institute of Marine Geology (QIMG) is one of the major coastal geological survey and research institutions in China. From the 1980s, QIMG participated in the coastal and offshore geological survey near Caofeidian area, with the priority of providing geological information for the oil exploration industries in this area. QIMG finished 1:50.000 and 1:100.000 bathymetry mapping, sub-bottom profiling and seismic survey, surface sediment sampling and drilling. Subsidence monitoring was carried out for a stability assessment of artificial islands for oil exploration. A GIS database provides multi-disciplinary geo-information. Today, QIMG continue working in this area with geological and geophysical technologies, such as sampling, drilling, seismic survey to provide shallow geological structure information in the reclamation area and in the near shore. This is especially concerned with the coastal sediment properties and transport, stability of the harbour and channels, neo-tectonic movement and engineering risk assessment, and environmental impact assessments.

In the Yangtze River Delta close to Shanghai, QIMG completed a 1:1.000.000 and 1:250.000 regional survey and mapping project, with integrated geological and geophysical methods, including surface sampling and coring, drilling, magnetic and gravity survey, bathymetry, side-scan sonar, shallow seismic profiling, seismic and hydrological survey and monitoring. This geo-information was used for planning the Donghai over-sea bridge and Yangshan Harbour.
Coastal and offshore monitoring of the impact of the Three Gorges Damming project on the Yangtze River Delta area has been carried out since 2002. Series data are collected and modelling studies have been carried out to forecast the long-term impact and provide solutions to coastal management problems including coastal protection. QIMG also carried out marine aggregates survey in neighbouring areas to identify sources of sand and aggregate for the construction and development of harbours and bridges. QIMG is also working on a submarine ground water survey project near the Yangshan Harbour and island area to provide fresh water supply to the islands lying some distance from the mainland.

The successful operations regarding the construction of large infrastructures in the coastal zone such as the Donghai cross-sea bridge, Yangshan Harbour, PuDong Airport, and Shanghai Harbour learned that a fundamental understanding of the geology and coastal dynamics can help to "Build with Nature (see CCC III-3-3-1). But the water pollution, rapid subsidence and sea water intrusion continuously tells us that the carrying capacity of the coast needs to be well considered during the planning and development of industrial and harbour infrastructure, and for addressing the impacts of climate change.

6. Conclusions

Over the last decades, China's coastal area has faced large-scale urbanisation and industrial and harbour development. These developments will increase in future and may cause serious environmental problems. These problems, including those associated with the potential impact of global climate change, must be addressed in a holistic way. China recognised this growing pressure in the 1990s and made institutional arrangements for developing ICZM.
ICZM, integrated spatial planning and Environmental Impact Assessments are very important mechanisms supporting the integrated planning and sustainable implementation of large-scale coastal projects.
Geoscientific research plays an important role in planning large-scale infrastructure projects, land reclamation and creating coastal eco-cities, as well as future adaptation to climate change impacts.
Applied geo-science has delivered knowledge and understanding efficiently to the Chinese policy/decision making community and the construction companies.

The Netherlands has shared its coastal hydraulic engineering and ICZM experiences with China specifically regarding coastal geo-science applications during the planning, design and execution phase of a number of large-scale infrastructure projects.

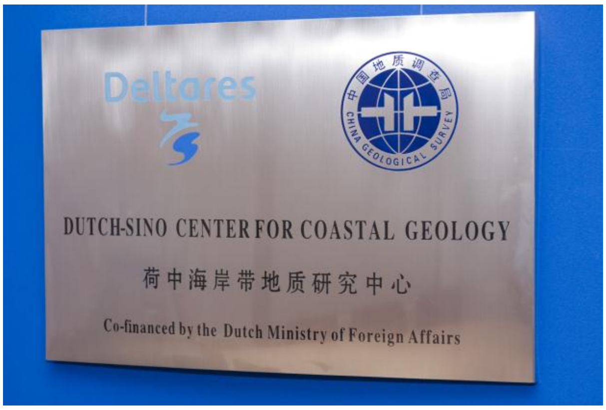

Figure 9: ***A formal cooperation between China Geological Survey and the Dutch Deltares*** *has been signed on September 11th, 2008 establishing the Dutch-Sino Centre for coastal Geology. (photos: Deltares)*

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