



Tang, Yu-Ting and Chan, Faith Ka Shun and Griffiths, Jim (2015) City profile: Ningbo. *Cities*, 42 . pp. 97-108.
ISSN 0264-2751

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Manuscript : City Profile - Ningbo

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Abstract

Ningbo is located in the south-east of Yangtze River Delta by the East China Sea, 220 km south of Shanghai. The city has been an important port in East China for foreign trade since 7th century. Since 1980s, encouraged by China's economic "open-door" policy, one of the ways the city attracted foreign investment and thus grew its economy was by establishing multi-functional economic development zones near its deep-water port. As a result, Ningbo is now one of the top ten coastal ports in the world (as measured in Twenty-Foot Equivalent Units, TEUs). Similarly, the city's GDP per capita is approximately three times the national average.

The current and historic prosperity of Ningbo is in no small way related to its geographical position, just 20 km inland from the Hangzhou estuary and the gateway to the East China Sea. It is also the approximate centre of a 1000 km² coastal plain, at the confluence of the Fenghua and Yao Rivers, and from where the Yong River leads to the sea. However, also a result of this geographic location the city is now facing an increasing risk of coastal flooding caused by increase in urban area; climate change (increased rainfall intensity); and predicted sea-level rise. As a result both water management and current flood management practice (and related infrastructure) are under scrutiny. In addition to describing the evolution of the city, this paper focuses on the implication of current planning practices in Ningbo, which aim to ensure the sustainable development of the city both in terms of its natural resources and its expected rate of economic growth.

Introduction

Ningbo is a major Chinese city located in lower corner of Yangtze River Delta (YRD) (Fig 1), ranging between latitude 28°51' and 30°33' N, longitude 120°55' and 122°16' E. Human activity in the area appeared relatively early: archaeological evidence from Hemudu (present-day Yuyao City Administrative district) indicates rice growing has existed in the area since the Neolithic era (about 5000 BC). The region was known as 'Mingzhou' between the 7th and 12th centuries and 'Qingyuan' between the 12th and 14th century, with the name 'Ningbo' only appearing since the Ming dynasty (1368-1644 AD). At that time, its general territories covered the region of Ningbo today, and Zhoushan archipelago, which has become a prefecture level city in its own right. By contrast, Yuyao County (now upgraded to a county-level city) was only added into the territory of Ningbo as recently as 1985.

Ningbo has been a city of both historical and economic importance in international trade since early 20th century despite being overshadowed by Shanghai which lies just 150 km across the Hangzhou bay. Since the first settlement in 200 BC, the location of Ningbo on the 'Marine Silk Road', coupled with the fact that it was very near a natural deep-water port, brought prosperity to both Ningbo and the lower YRD as a whole. The current population of Ningbo is 7.5 million, and the city enjoys the special designation of a 'separate planning city' which grants it provincial level administrative status. This also means that powers and responsibility for integrating the progression of industry development with various aspects of urbanisation are allocated to the city government (Tanner et al., 2009). The municipal government of Ningbo thus bypasses the Zhejiang Provincial government, and directly reports to the central government in Beijing (Tanner et al., 2009).

Similar to other populous coastal cities of the region, continuous agglomeration of the population, frequent cyclonic effects (typhoons), and climate change exacerbate the risk of drought and flood. In profiling Ningbo, we first highlight the influence of geographical factors that attracted immigrants to the area. We then evaluate the combined effect of increasing population and the climatological characteristics of the region, both of which increase the susceptibility of the city to flood and drought. The accelerated agglomeration of the city since 1980 has led to an increasing need for preservation of available water resources and improvements to flood management. We therefore review a number of initiatives that the Ningbo Planning Bureau has implemented to mitigate these issues. Further challenges facing the city with respect to the increasing probability of extreme weather resulting from climate change are also discussed.

Current Administrative Organisation

This paper describes the region that the Ningbo city administration governs today (Fig. 1): Ningbo city (six districts), two counties (Xiangshan and Ninghai), and three country level cities (Yuyao, Cixi and Fenghua). Amongst the 7.5 million people in Ningbo, roughly one-third of them reside in metropolitan areas. The oldest districts surrounding Sangjiangkou (the intersect point between Fenghua, Yuyao and Yong Rivers), are located at the centres of Haishu, Jiangbei, and Jiangdong districts. Highest population density are still in the city's commercial centre (Haishu), while the relatively new Yinzhou district is the largest in terms of area and total population (see Table 1). However, recently, the city government has gradually reallocated itself from Haishu to Jiangdong district, implying the intention of the government to stimulating further development outside Sangjiangkou. Beilun and Zhenhai with major harbours are the lifeline of the city for international

trading. The two harbours are expected to play a vital role for continued economic development of the city with the 'marine economy' commanding greater emphasis in the government's 12th Five-Year Plan (Ningbo Municipal People's Government, 2011).

The population density of counties and county-level cities within the municipality are much lower (see Table 1), coinciding with lower level of industrialisation. However, because of the relatively unaltered marine environment along parts of the costal line, especially Xiangshan, the planning authority suggests developing such areas as marine tourism destinations (Ningbo Urban-Rural Planning Research Center, 2011).

Weather and Climate

Ningbo has a subtropical climate: summers are hot and humid and winters are relatively dry with occasional snow. The humidity peaks in June when the Asian plum-rain monsoon moves in. A stronger or weaker summer monsoon period in any year can result in flooding or drought respectively (Ningbo Meteorological Gazetteer Editorial Board, 2001; Ju & Zhao, 2005). From August to October, the rain brought by typhoons becomes the dominant water supply; without typhoons, the area is at risk of drought. When typhoons occur, most low-lying areas and some river valleys are susceptible to flood. This risk of flood and drought during the harvest season is still a threat to the economy of modern Ningbo as surface-water remains the main water source for both industry and domestic use (Chen, Xu and Fu, 2007). Nicholls, et al. (2008) showed that 299,000 people are exposed to the risk of flooding, but this could increase up to 3.3 million by the 2070s due to climate change and rapid demographic expansion across the floodplain. Indeed, Ningbo is in the top twenty global port cities at high risk of coastal flooding (Nicholls, et al., 2008 & Hanson, et al., 2011).

Historical Development

The Shift of Political Centre

The floodplain on which modern Ningbo currently rests would not initially have been considered ideal for habitation because of frequent sea water intrusion and risk of drought. Additionally, whilst practicing agriculture, the Neolithic Hemudo people lived in stilt houses to adapt to frequent flood of the areas around Ningbo (Shang et al., 2006; Wang et al., 2010). By the early Qin Dynasty (212 to 206 BC), with several thousand people residing in the region, three county level administrations were established close to river valleys at the edges of the Ningbo floodplain (Baidu, Chengshan, and Tonggu, as depicted in Fig 2) (Lu, 2007).

The establishment of the city on the flood plain then, was the result of a series of overcrowded conditions in the more inland areas. A politically-motivated migration of people was initiated by a Chinese emperor (Southern Liu Dynasty, 460 AD) to move less affluent people to the area (Lu, 2007). These first settlements continued to attract immigrants, whether for conducting business or just avoiding the wars in the North. The Mingzhou prefecture, independent of nearby Shaoxing, was established during Tang Dynasty (738AD). The old prefecture capital, Xiaoxi (now called Yinjiangzhen), to the south west of the current city centre (Fig. 2), was superseded when the river valley near Xiaoxi could no longer accommodate population increase. The administrative centre was moved to north to where the Fenghua and Yao River converge at approximately the centre of the

Ningbo flood plain (known as Sanjiangkou) (821 AD). This location (in the Haishu district of modern Ningbo) has been the city centre ever since.

This pattern of development from the mountain foothills and valleys to the coastal plain indicates that living higher up the catchment in river valleys became a less viable option, particularly as the demand for land grew with population increase. Moving from the foothills to the floodplain however, meant that adapting to frequent flood and tidal inundation became a necessary evil at a relatively early stage of the city's development.

Development of Trade

Despite increased risk of flood and tidal inundation, the proximity of Ningbo to the coast has improved the opportunities for international trade. In 999AD, the city was already an important hub on the Marine Silk Road. Subsequently, when the capital of Chinese empire moved to the outskirts of Hangzhou (1138-1276 AD), Ningbo became the most convenient harbour to receive diplomats from South and East Asia, and particularly for trade collaboration with Japan. This promoted further agglomeration, with Ningbo becoming one of the biggest trading centres in the world by the 16th century, (which coincided with Age of Discovery in the western world). However, intermittent bans on maritime activities, imposed to curb piracy, sporadically affected the prosperity of the city. After the Opium war, the city was rapidly reopened to foreign trade. Most of the foreign businessmen resided in Northern areas of Sangjiangkou, known as Jiangbei districts in modern Ningbo.

It was around this time, when water transport was much faster and cost-effective compared to the land transport, that Ningbo's well-developed river and drainage-channel system (that allowed connection of marine and inland transport), became of strategic importance to Ningbo's economic development. Indeed, Ningbo's unique deep-water coastline is still a significant advantage for the development of the city's maritime industry today (Gu et al., 2011).

Rapid Industrialisation

After the economic reforms of China in late 1970s, Ningbo once again became ideally located to exploit trade-friendly policies promoted by the central government (i.e. open-door policy in 1979). Since then, manufacturing industries have blossomed, and GDP contributed by secondary and tertiary industries has increased dramatically (Fig. 3). By 2009, the agriculture output contributed only 4.4% of the total GDP, while the secondary and tertiary industries contributed 53.3% and 42.3% respectively (Bureau of Statistics of Ningbo, 2010). Such strong economic growth, symbolised by a GDP per capita of \$10,068 USD for the Ningbo residents (90% that of Beijing or Shanghai in 2010 (Ningbo Urban-Rural Planning Research Center, 2011a)) also served to fuel internal migration from other provinces in China. The average annual population growth rate was estimated to be around 0.7% since 1978 (Bureau of Statistics of Ningbo, 2011) but in the latest decade, it was more than 2% each year. By 2010, more than one third of the population of the Ningbo metropolitan area was classed as non-local (roughly 2.3 million people, based on the investigation for the sixth national population census, Ningbo Urban-Rural Planning Research Centre, 2011).

From 1978, to the mid-1990s, Ningbo's GDP growth was frequently above that of the national average (Ningbo Urban-Rural Planning Research Center, 2011). Since 1997, a slowing down of GDP growth has resulted from over-emphasis and focus on industrial development rather than

promotion of the high quality service sector (Ningbo Urban-Rural Planning Research Center, 2011). The service sector contribution to GDP has been relatively low compared to the other major cities in China. While the contribution of the service sector in Hangzhou exceeded the industrial sector by 2010 for example, Ningbo's service sector still contributed 10% less than the industrial sector in 2012 (Fig 4). It can be argued therefore, that over-valuation of industrial sector may have sacrificed the environmental quality and livability of the city, and as a result discourage the human capital needed for service sector development.

Harbour and Associated Development with Marine Logistics

Development of Water Network

To accommodate the growing demand for freshwater during the development of the early Ningbo city, many artificial water channels, dams, weirs, water gates were established across the region. Whilst water ways were primarily developed for irrigation, the design also allowed desalination of water in the seashore lagoons, acted as a defense against seawater intrusion, stored fresh water for use in times of drought; and facilitated associated water transport (Griffiths, Chan and Tang, 2013). Ta Shan Weir near Yinjiang (Yin River) constructed in 833AD is symbolic of the hydro-geological engineering achievements at the time. The construction of such wide-scale water infrastructure and control systems represents a significant human effort to alter the estuarine environment to increase available water resources (Chen, Xu and Fu, 2007).

Converting established lakes and ponds into agriculture fields had been common practice along Yangtze River Basin, especially after the large amount of immigrants moved from the north during the South Song Dynasty (Lu, 2007). However, the consequences of such practice could prove to be detrimental in times of drought. The disappeared Guangde Lake is a much discussed case in Ningbo (Shao, 1985). Today, in the area of Guangde Lake, one of the major new towns with sizable industrial parks stands. Disconnecting water channels or draining the water bodies have still been practiced under the name of urban development as of today (Chen, Xu and Fu, 2007).

Harbours

The geographical advantages of marine transport and trading have been an important driving force for economic growth of Ningbo after economic reform. As marine transportation and technology has developed, Ningbo's ports and harbours have played an increasingly significant role in international trade. The throughput of cargo and containers has seen steady increase since economic reforms (Fig. 5). In 2009, the throughput of Ningbo harbours was 383,850,000 tons, of which 73,235,975 tons were cargo containers (both figures ranked in top ten in the world). The value of direct imports and exports has also seen a significant increase. In 2009, more than nine out of ten containers shipped globally were through international shipping lines that operate via Ningbo (Bureau of Statistics of Ningbo, 2010). In addition to Ningbo's ports and harbours, industrial parks, export processing zones and tax-protected zones have been established along the coastline (the earliest was dating back to 1992).

Towards Further Development

Ningbo is now seeking to further upgrade the quality of the maritime institution. For example, in 2011, mass commodity trading platforms were established for trading of raw materials and

chemicals (Ningbo Commodity Exchange). Similarly, maritime trading platforms were established for trading ships and shipping related business (Ningbo Shipping Exchange). In the same year (in collaboration with Shanghai) Ningbo harbour proposed to initiate the first maritime insurance company to strengthen the soft trading infrastructure of Ningbo.

However, many of the infrastructure and institutions that have been developed in Ningbo are now seen as being outdated and need of upgrade. In particular, information technology and associated networks have not been developed fast enough to support the development of tertiary sectors which are critical for modern commerce and trade, including the logistic industry, insurance in marine transportation, and marine affair arbitration (Ningbo Urban-Rural Planning Research Center, 2011).

Adaptation to Environmental Change

The development of the floodplain around Sanjiangkou was out of the necessity, to accommodate population growth and subsequently to facilitate Ningbo as a centre of trade and commerce. As Ningbo continues to expand, both economically and geographically, it is becoming vital for the city to establish a comprehensive planning and management system to reduce the impact of risks imposed by nature hazard (typhoon, flooding, tidal inundation). At the same time there is increasing pressure to further expand and optimise the function of Ningbo's the harbor and port areas.

Situated so close to China's eastern seaboard, Ningbo is especially sensitive to meteorological phenomena during the typhoon season when storm surges and intense rainfall account for 70% of the annual precipitation. Historically, this has resulted in coastal and fluvial flooding. More than 44 typhoons were estimated to have visited the city since 1950s, causing 12 coastal floods (Tong et al., 2007), resulting in a total economic cost more than 93 billion RMB. Cai (2002) noted typhoon "Winnie" in 1997 unleashed more than 300mm of precipitation in 24 hours and had a surge height of 4.54 meters. As a result, 165 km of coastal embankments were breached and damaged; sea water immersed and inundated more than 80% of farmland (about 260,000 ha) in Yinzhou and Fenghua, causing more than 4.5 billion RMB worth of damage (at 1997's rate) (Ningbo Daily, 2012). Evidently the city has suffered from frequent and severe flooding of last two decades (Table 2). Similar to other Chinese coastal populous city, Ningbo was rapidly urbanised (Chan et al., 2012), which means that an increasing urban population and their assets are substantially exposed to surface water and pluvial flooding (e.g. 2013, 2012, 2011 and 2009 floods). Significantly, these floods particularly impacted urban districts (i.e. Jiangbei, Yinzhou, etc.) shown in Table 2.

Recently, typhoon "Fitow" between 7th to 13th October, 2013, generated a large storm surge and intense rainstorm (1-in-100 year return period) that affected nearly one-third of the population of Ningbo (2.48 million), and caused direct economic losses of over 33.3 billion RMB (Pan et al., 2013). This event also exposed the city to pluvial flooding as runoff overloaded the city's drainage capacities (Yinzhou district recorded 418mm/24hr, the highest record since 1949). As a result, over 70% of roads in major urban districts were flooded. However, current Ningbo flood protection guidance (established in 2000), only address coastal (from storm surges) and fluvial (from river) flooding and landslides. Surface water and pluvial flooding (that caused by overland flowing flood water from urban drainages and channels), remain overlooked (NBJD, 2014). At present, the low level urban drainage system (designed for 1-in-20 year events) proved is to be insufficient (Tanner et al., 2009).

Somewhat ironically, the city is also susceptible to drought during the autumn and winter, due to relatively low precipitation (less than 300mm): 11 drought events were recorded since 1949 (Tong et al., 2007). The problems caused by drought are twofold: a shortfall in available water, and the concentration of pollutants in the aquatic environment. Both these situations are exacerbated by industrialisation and urbanisation. The following sections review the actions taken by the city to improve infrastructure for mitigation flood risk and safeguard of water quality.

Planning for Flood

The significant risk of flood breaching the walls and embankments of the city during extreme weather conditions has catalysed the municipal government to implement various mitigation strategies. A “rainfall warning communication system” was established in 2007, which allows the Ningbo Meteorological Bureau and Water Bureau to broadcast flood related information collected from over 300 hydrological telemetry stations in the city (Tanner et al., 2009). The system is activated when precipitation exceeds 30mm/hour, and warning notices are delivered to related sectors for adequate response. This system was built on the success of avoiding casualties when several typhoons (Kanu, Saomai and Bilis) struck Ningbo in 2005 and 2006. Whilst the system was implemented relatively quickly to reduce the loss of life and assets, it cannot prevent damage to weakening infrastructure, real estate, farmland and industrial property.

For the long term flood prevention, the planning authority has proposed two major construction projects. The first is to divert the fluvial flood water into the sea before it enters the urban area (Ye, 2013) (Fig 6a.). Currently, the fluvial flood from Yao River or Fenghua River has to pass through Sanjiangkou to enter the sea. A typhoon related storm-surge will usually occur concurrently with the fluvial flood peak and thus reduce water discharge from the city centre to the sea. Creating channels to divert fluvial flood water away from the city centre will reduce the risk of the city being inundated by flood waters from mountains and sea simultaneously.

Secondly, the forced drainage system within the city centre where the flood risk is high may be the only way to protect the urban areas from storm-surge inundation (if relocation of the residents is not a feasible option). Figure 6b demonstrates the forced drainage system that would need to be introduced in the low elevation areas within Jiangdong district, based on the analysis of the Ningbo Urban-Rural Planning Research Center (Ye, 2013).

Safeguarding Water Supply

In the last 15 years, significant improvements have been made to the water-management infrastructure of the city (funded by both national and international agencies including the World Bank). By 2005, the total water-supply capacity within the Municipality had reached 21 billion m³. Surface water infrastructure had also been improved by the renovation of over nine-hundred sluices and 800 km of river dyke and sea pond; repair of more than 3,000 km of river course; and the development of 185,000 KW of mechanical and electrical irrigation and drainage power (addressed in the briefing documents by Ningbo Municipal Water Conservancy Bureau, <http://slj.ningbo.gov.cn/NewsList.aspx?CategoryId=19>). However, whilst the Ningbo Water Supply Company (NWSC) served 1.3 million people in four urban districts with a treatment capacity of 820,000 m³/day, a significant number of people were still obtaining water from small-town supply

systems (up to 610,000 m³/day) or through self-supply (460,000 m³/day) which often drew on heavily polluted surface waters that were subject to occasional saline intrusion (World Bank, 2011a).

The Ningbo Municipal government has responded to increasing water demand (resulting from both industrialisation and urbanisation) by developing a city-wide water transfer scheme that aimed to provide water to both the inner urban-areas and the surrounding small town network (Browder 2007). In 2004 and 2005 respectively, the Zhejiang Urban Environment Project (ZUEP) and the Ningbo Water and Environment Project (NWEF), were approved by the World Bank (World Bank, 2011a; World Bank, 2011b). NWEF deliverables included the construction of the Zhougongzhai Reservoir; construction of a new raw-water intake tower in the Jiaokou Reservoir, and a 500,000 m³/d water treatment plant at Maojiaping. The project also included a 9.6 km tunnel from Jiakou Reservoir; two additional wastewater treatment plants (in Cixi, 100,000 m³/d, and at east Ningbo, 50,000 m³/d); a 47 km ring-main around Ningbo City with supporting network of treated transmission pipes; an associated sewer collection system (consisting of 58 pump stations and 230 km of the pipes); and technical assistance to improve city water planning, utility price and service regulation. The planning Bureau aimed to increase the capacity of water supply and treatment plants to 3,000,000m³/day by 2020 (Ningbo Planning Bureau, 2006). If successful, the per capita water resources in Ningbo (estimated to be 1,163 m³ by Lee, 2005) will move closer to the internationally recognised water scarcity standard of 2000 m³.

Urban Flood and Water Quality management

A 3.3 km eco-corridor currently under construction in the eastern part of the city has been touted as a blueprint for future flood risk management and water quality improvement (see Fig 7a.). The corridor, consisting of an associated mixed-use urban development will cover six square miles. Designed by the SWA Group from Sausalito (CA), the project has been a part of the 'East New City' (the new administrative centre of Ningbo in Jiangdong district) in Ningbo Planning Bureau's master plan since 2002, and its concept and design won the "Honor award" of 2013 ASLA professional Awards.

The concept of the project is to restore old water canals that were degraded or damaged during industrial development, and to increase the connectivity between Dongqian Lake (located further east of the centre) and the Yong River (where it flows out of the city and towards the sea). By reconnecting the older drainage channel systems, water quality is expected to be improved by increased frequency of replenishment. Furthermore, surface-water features are designed to meander through a series of streams, ponds and marshland (for example, the marshland pictured in Fig 7b.) to allow native wetland ecological community sufficient time to decompose pollutants in the water. The goal of this project is to improve surface-water quality from class V to class III in Chinese standard (ASLA Professional Awards, 2013). In addition, "retention basins" and "rain gardens" have been designed in several locations (see Fig. 7c. and Fig. 7d.) where the land will be accessible during the dry season, while during the typhoon season, it will serve as floodable areas to mitigate the water-level rise. A storm-water run-off collection system is also planned to harvest and retain the water and direct it through the permeable ground to replenish groundwater or create time lag for water to flow back to flood storage areas or streams. Such practices structures should offer improved flood mitigation, utilisation of stormwater resources, reduction of pollutants from urban drainage and creation of more green spaces.

Challenges to Future Development

As an emerging and increasingly important commercial and port city in SE Asia, Ningbo continually needs to adjust its position, both in China and the rest of the world, in response to national politics, global economic fluctuation and rapid demographic changes. However, recent efforts from the government and international organisations to improve the city's water management infrastructure may not yet be keeping pace with the speed of urbanisation and industrialisation. The possible risks to continued city expansion and development of a sustainable economy, in the face of increasing environmental uncertainty are therefore discussed below.

Climatic and Anthropogenic Impact

Historical records of flood and drought have become increasingly detailed since the social and economic importance of Ningbo has grown, and as technology related to measurement and recording of climatic events has advanced (Fig. 8) (Ningbo Meteorological Gazetteer Editorial Board, 2001; Griffiths, Chan and Tang, 2013). The apparent increased frequency of such events could also be the result of greater interaction between human societies and the natural environment. Hanson et al. (2011) ranked Ningbo one of the top 20 global coastal cities (ranked 17 in 136 cities) susceptible to flood risk based on not only the geographic characteristics but also current degree of population increase, and assets (GDP) accumulation. Given the trend of population and economic growth continue the exposure and vulnerability will be even higher (14 in 136 cities) in 2070.

Globally, sea-level is estimated to rise between 0.6 and 2 metres by the end of 2100 depending on different climatic and economic scenarios (IPCC, 2007, Vermeer & Rahmstorf, 2009). In addition, the frequency and magnitude of cyclones in the West Pacific Ocean region has been increasing since the 1950s (Webster *et al.* 2005). Projected extreme climate-related events therefore, combined with the expected increased sea-level, suggest that more powerful storm-surges and rainstorms will occur in the East Asian region. Indeed one of the largest floods in a generation was caused by Typhoon Fitow in Ningbo as recently as October 2013. The flood inundated nearly 100,000 homes and cost over 20 billion RMB economic loss (China Daily, 2013).

The risk of flooding is increased by regional land subsidence. The total accumulated subsidence due to groundwater extraction in Ningbo has reached over 485mm in 2002 since 1960, affecting 175 km² of the city (Yin, Zang and Li, 2006). Most of the coastal cities in Eastern China are expected to continue subsiding due to the increased compression on soil layers that result from urban construction and development (Xue *et al.* 2005). It is suggested that the current rate of subsidence (average 12mm/year), in combination with rising sea level, will result in a substantial increase in the risk of coastal flooding (Hu et al., 2009; Xu et al., 2009).

Assessing multiple natural hazards in Yangtze River Delta, Liu *et al.*, (2013) observed that Ningbo experienced an increased occurrence of the 50-year return period floods between 1950 and 2010. Current flood protection measures may therefore be unable to mitigate hazards at future frequency and magnitudes. Chan et al., (2012) noted some 300,000 people and US\$9.3 billion economic assets are currently exposed to coastal and fluvial floods in Ningbo. However, the current flood protection design standard in Ningbo is for storms with return periods up to 20 years (e.g. the whole Fenghua

catchment is only protected against 5-year return period storms) though the planning bureau plans to increase the protection level to consider storms with return periods up to 200 years in areas prone to coastal flood (i.e. Sangjunkou) that has recently addressed in the *Ningbo Strategic Plan 2020* (Ningbo Planning Bureau, 2006). The current protection level is apparently not enough to protect the city from seasonal cyclonic effects (Jin, 2008). Without improvements to more resilient protection and climate change adaptation measures (in a reasonably short period), more people and their economic assets (i.e. properties) could be exposed to flood risk projected population increases to 3.3 million and economic assets reach \$US 1,000 billion.

In light of rapid urbanisation and climate change then, design and implementation of a coastal flood risk management plan (CFMP) may be the best way to reduce flood risk whilst also incorporating a land-use planning strategy (Chan et al., 2013). A robust CFMP would help practitioners make better long-term decisions on land-use development in coastal flood prone areas (e.g. conserving wetlands for flood mitigation). The enriched marine ecosystem and economy is especially vital for delivering the principle of sustainability. Whilst it is impossible to relocate existing developments back to upland areas, the concept of CFMP allows government authorities and developers the opportunity to plan for known flood risk (i.e. understand and address potential flood risk spatially in relation to known population and economic assets), and to establish an adequate adaptation plan to mitigate future flood risk.

Growing Industries and Water Quality Protection

The GDP composition of Ningbo is still dominated by heavy industry. Half of the top twenty businesses classed as having 'high' annual revenue in Ningbo for example, are related to steel, chemical and petroleum in 2009 (Bureau of Statistics of Ningbo, 2010). Current foreign investment is also targeting these industries (Ningbo Urban-Rural Planning Research Center, 2011). The dominance of this sector affects environmental quality and pushes population growth as such manufacturing industries require intensive labour. The reliance on this sector in the long-term therefore creates the dilemma between maintenance of economic growth and protection of the environment. Without doubt, the shift from an industrial dominated economic to a more balanced or service-sector led economy would do much to reduce anthropogenic environmental impacts. Surface water quality in particular has greatly deteriorated over last 30 years at least partly as the result of increased discharges from industry.

According to Chen, Xu and Fu (2007), the surface water network (including natural water bodies and artificial canals) should be at least 5-8% of the urban area to maintain their 'self-purification function'. Unfortunately, the surface-water network has shrunk below this standard in Ningbo city centre since 2003 as the result of rapid urbanisation. As such, projects such as Ningbo's 'Eco-Corridor', described above, would ideally be implemented across a larger scale and in multiple sites to remediate the situation. Indeed, the Ningbo Planning Bureau (2006) has recently declared the intention to establish three similar types of development in greenbelts in the briefing documents of their current master plan. However, issues related to land reclamation will always be sensitive to stakeholders such as the tenants and land owners, which could make it difficult to repeat similar projects effectively. The fact that the current eco-corridor project has only reached half completion since its initial planning more than ten years ago is perhaps indicative of the complexities involved. To facilitate implementation therefore, it might be more practical to apply concepts of the designs

used within the eco-corridor at smaller scales across the city whenever possible – for example, increase rain gardens along the existing banks of water channels or reconnect channels to create a greater number of routes for water meandering where appropriate.

Conclusion

History shows that the establishment of modern Ningbo at its current location between 500 and 700 A.D. was at least partly because of population growth, and partly because the time was right for development of international trade when the Chinese emperor was looking to develop diplomatic and trading relationships to the east and south. More recently, the city has experienced significant industrialisation and urbanisation since the economic reform of China in 1979, and is now shaping itself into one of the growing coastal mega-cities in the Yangtze River Delta region. To maintain its economic competitiveness, the city now needs to carefully consider how to rebalance the development of industrial and service sectors and succeed in becoming an established post-industrial city so that it can begin to take greater advantage of its geographical location; natural deep-water harbours; and its close proximity to international shipping lanes.

The rapid development and urbanisation of the last 40 years however, have created potential problems for the environment and water management. In addition, current climate and sea-level scenarios suggest an increased risk of extreme events and flood risk for the city. Whilst economic growth remains one of the priorities for the municipal government, it also recognises that it is necessary for Ningbo to sustain itself with a well-designed and maintained water and environmental management system, flood control strategies, and reliable water infrastructure. The Ningbo Planning Bureau for example, has demonstrated the knowledge of water management in some exemplary initiatives to adapt to the consequences of climate change and man-made environmental alteration. The vital issues are whether such knowledge and plan can be implemented within reasonable timeframe to catch up with the speed of urban expansion and climate change.

The physical alteration of environment due to urbanisation and increased population also significantly increase the risk of both flood and drought. Therefore, although Ningbo was well-located for its development as trade hub and industrial powerhouse, it now needs to be mindful not to become a victim of its own success. Careful planning of further urban and industrial expansion is required, as will be projects that upgrade the environmental and water management infrastructure. As the municipal government has been given a higher status than the most provincial cities in China, the Ningbo Planning Bureau has the opportunity to exercise its power to implement a unique and comprehensive plan for the future. Effective institutional arrangements and planning however, will be the key to delivering such plans, and to securing safe passage of the city as it enters its next stage of development. If all these things happen Ningbo may then become a successful example of how adaptations to both anthropogenic and environmental change can be achieved in a sustainable manner.

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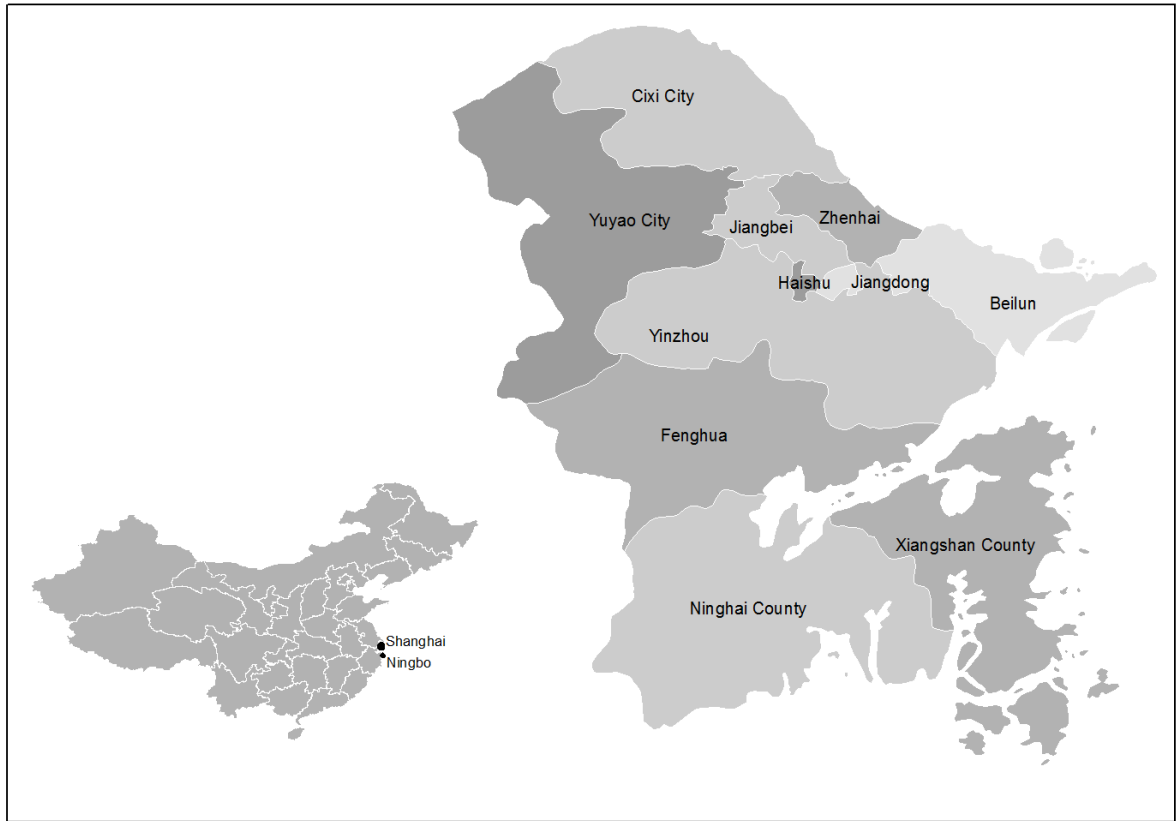


Fig. 1. The Administrative Areas of Ningbo in Relation to China. Source: Plotted by Authors.

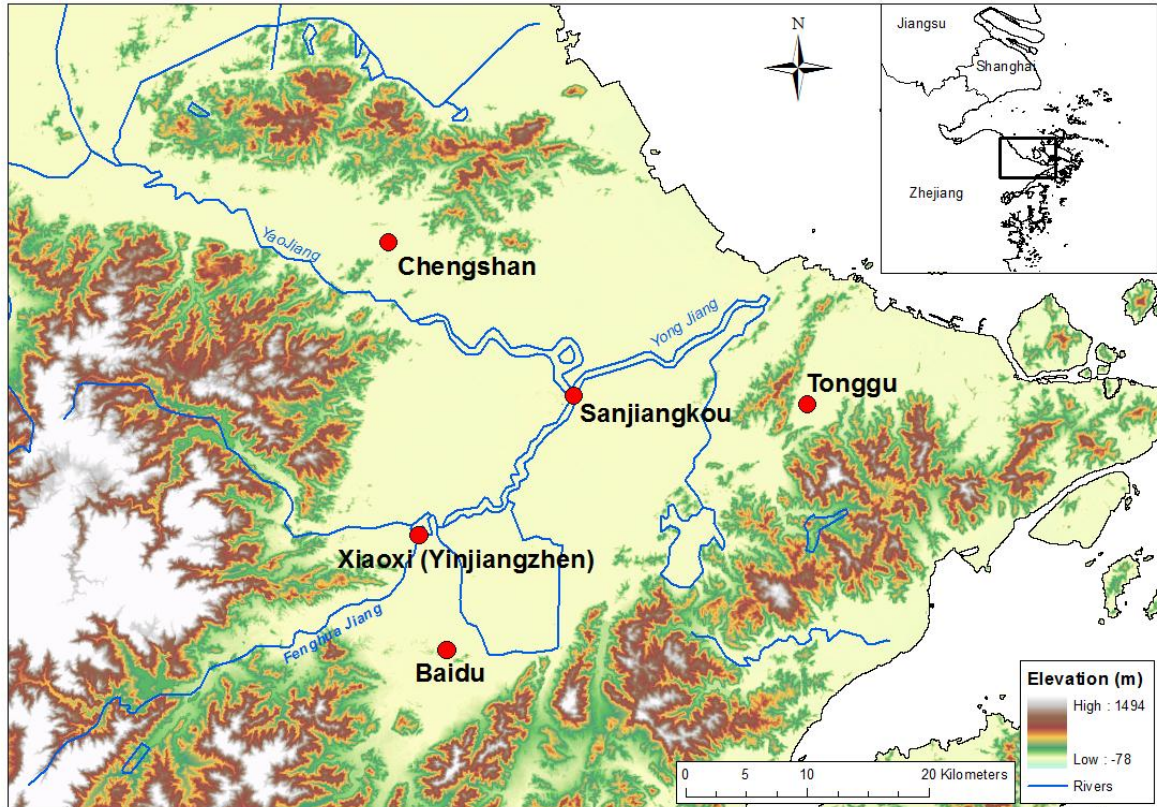


Fig.2. Locations of YinJiang in Relation to Yuyao Plain and Ningbo Plain. Source: Plotted by Authors.

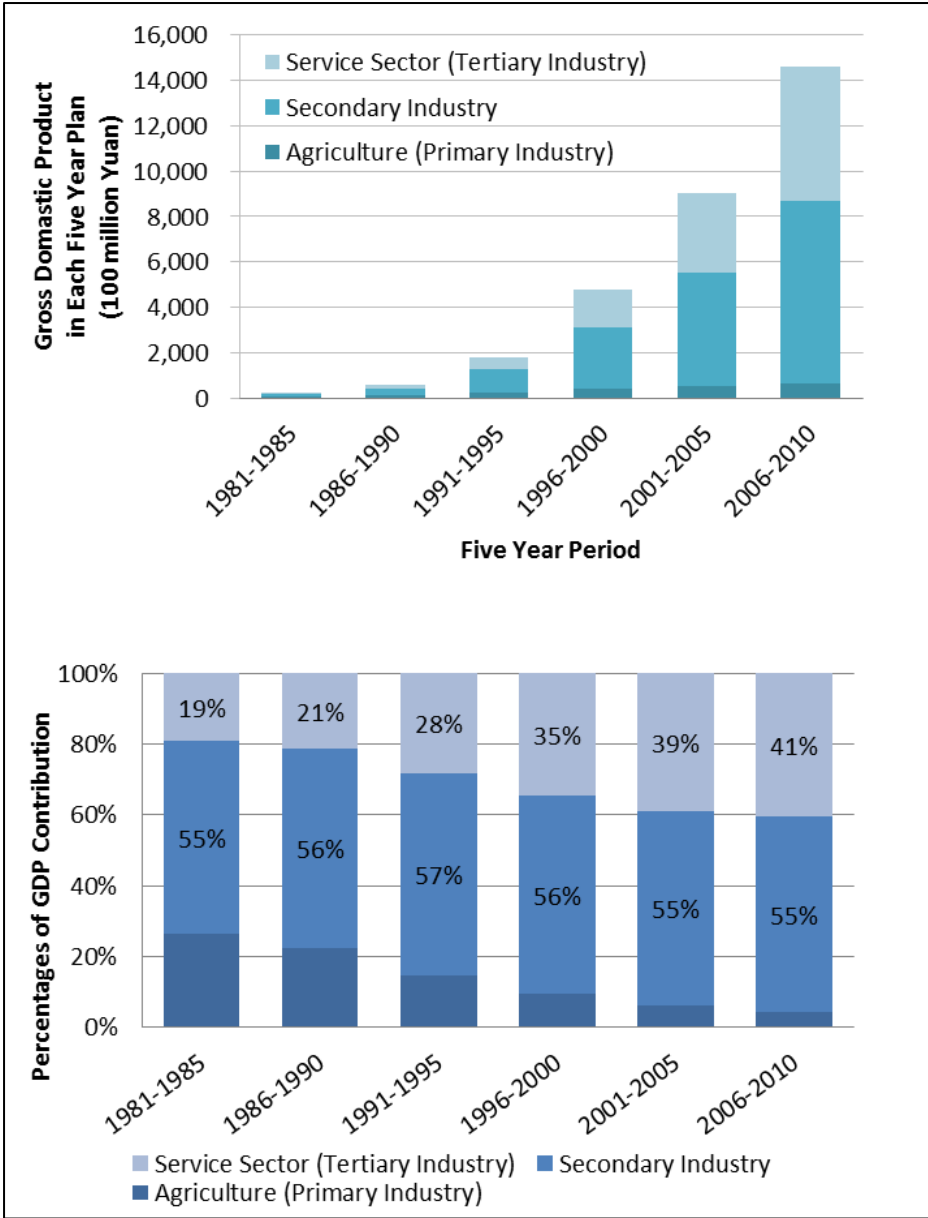


Fig. 3. The GDP Contributions by Three Tiers of Industry in Ningbo. Source: Plotted by Authors based on Data from Bureau of Statistics of Ningbo(2010).

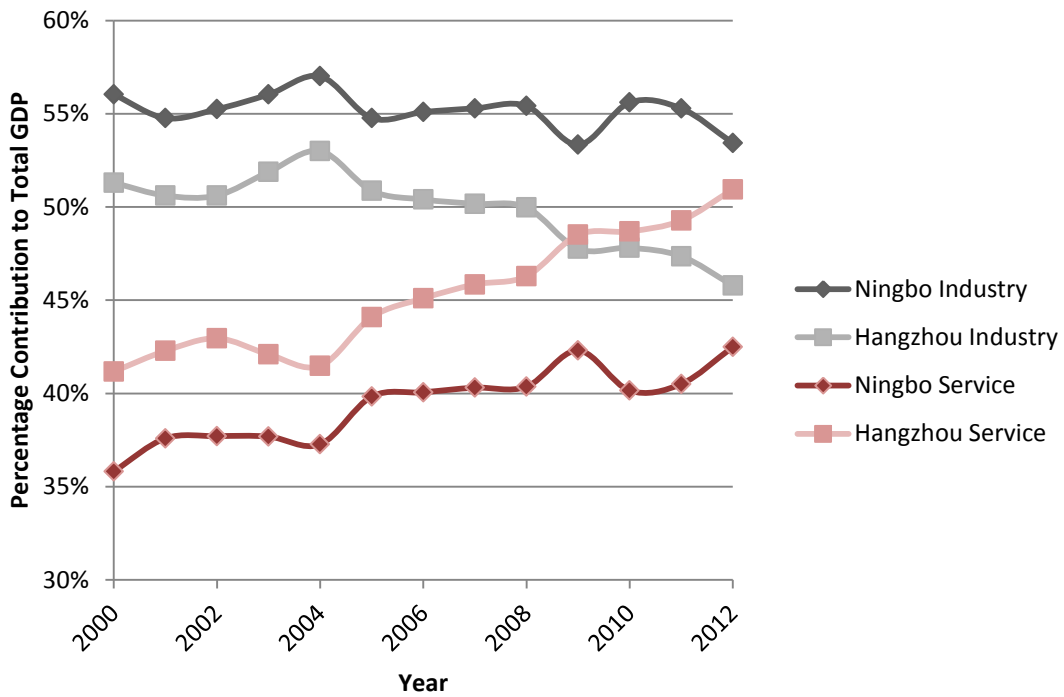


Fig 4. The Comparison of the GDP Contribution by Sectors of the Biggest Two Cities in Zhejiang Province since Millennium (gray lines: the percentage contributed by industrial sectors; red lines: the percentage contributed by service sectors; ◆ Ningbo; ■ Hangzhou). Source: Plotted by Authors based on Zhejiang Statistical Year Books between 2000 and 2012 by Zhejiang Statistical Bureau.

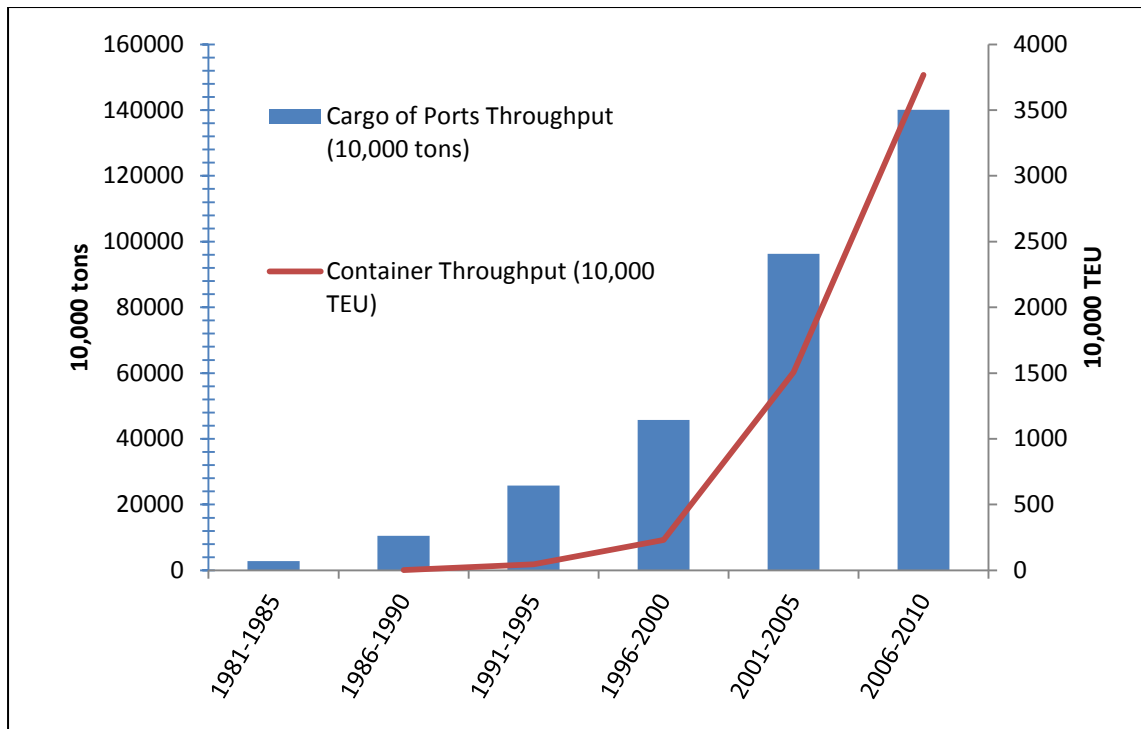


Fig. 5. The Increase of Capacity of Ningbo Harbour during Various Five-Year Plan periods. Source: Plotted by Authors based on Data from Bureau of Statistics of Ningbo (2010).

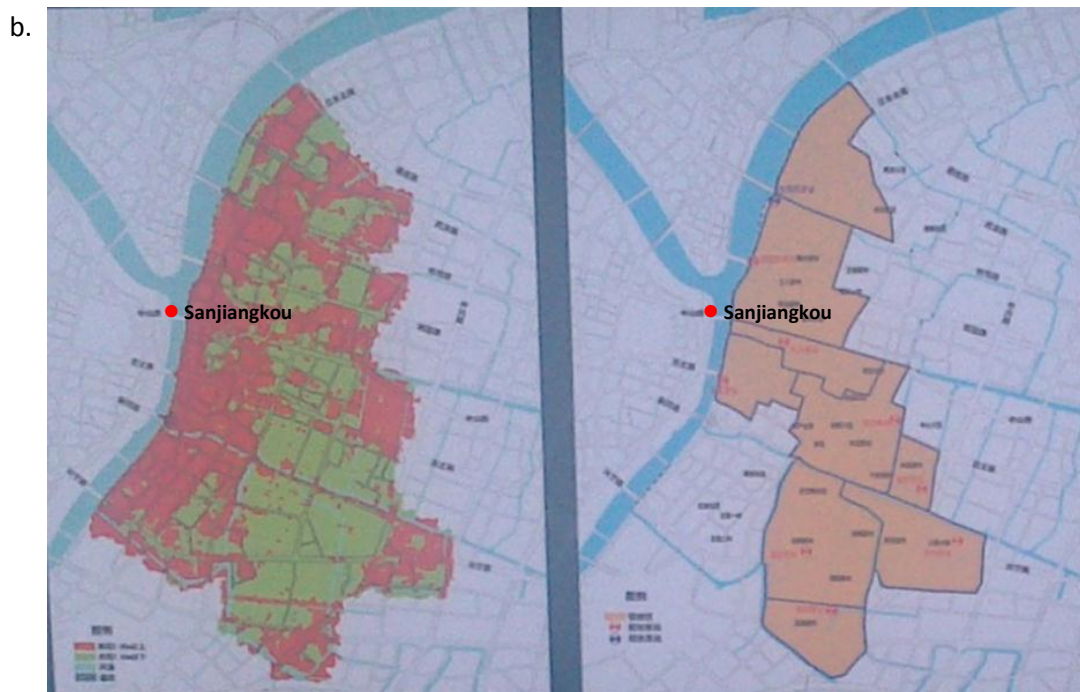
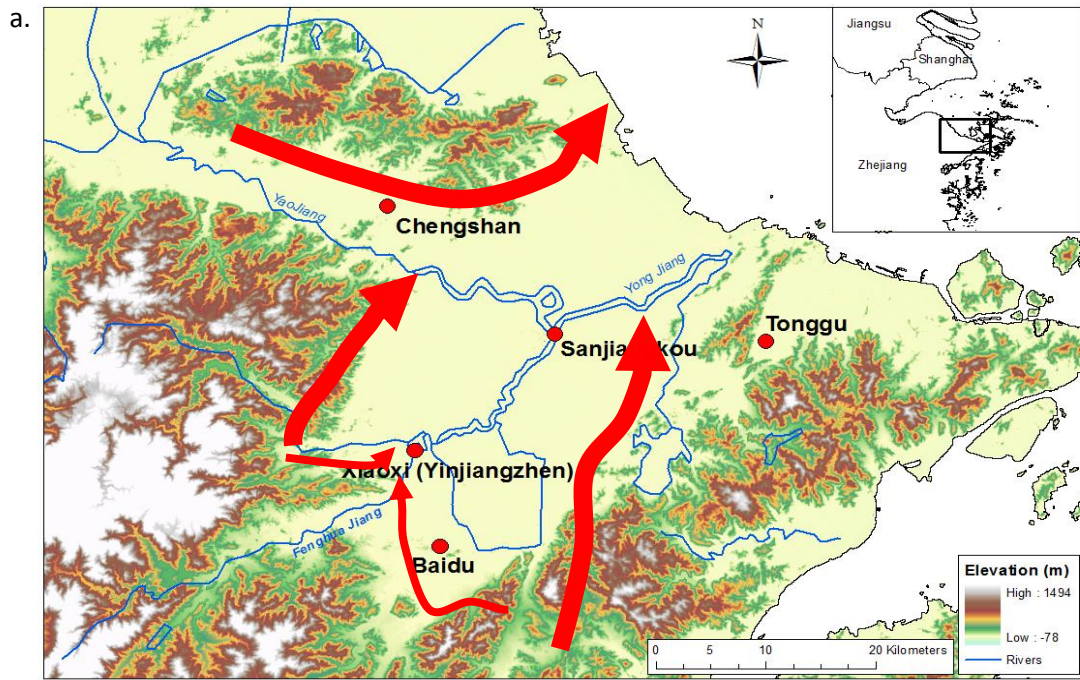


Fig. 6. Proposed Measures to Reduce or Prevent the Damage Caused by Flood. **a.** The proposed of water channels (indicated by red arrows) to divert the fluvial flood water from Sanjiangkou, the commercial centre of the metropolitan in Ningbo. Source: Author's sketch based on the presentation made by Ye (2013). **b.** The proposed areas in need of more forced drainage systems (marked in light orange in the right plot) in comparison to the relatively low land (marked in green in the left plot) in Jiangdong district, within the range of Sanjiangkou. Source: Pictures Taken by Authors in the post section during the workshop on January 15, 2013, Ningbo.



Fig. 7. Planned and Established Eco-corridor in Ningbo Area. **a.** relative scale and locations of the 3.3 km exemplary eco-corridor (white block), the three planned eco-corridor with the function of 5 to 10 km width greenbelt of the city (dash lines) and the areas seriously affected by the flood in the city centre (pink shading area). **b.** A recreated marshland area in the established part of the eco-corridor. Source: Picture Taken by Authors. **c.** The map installed in one section of the new Eco-corridor. The red arrows indicated the locations of water retention facilities for flood control in this section; the blue patches are the water bodies in the corridor. **d.** Rain Garden during the Dry Season. Source: the publicly available satellite image modified by authors and pictures taken by authors.

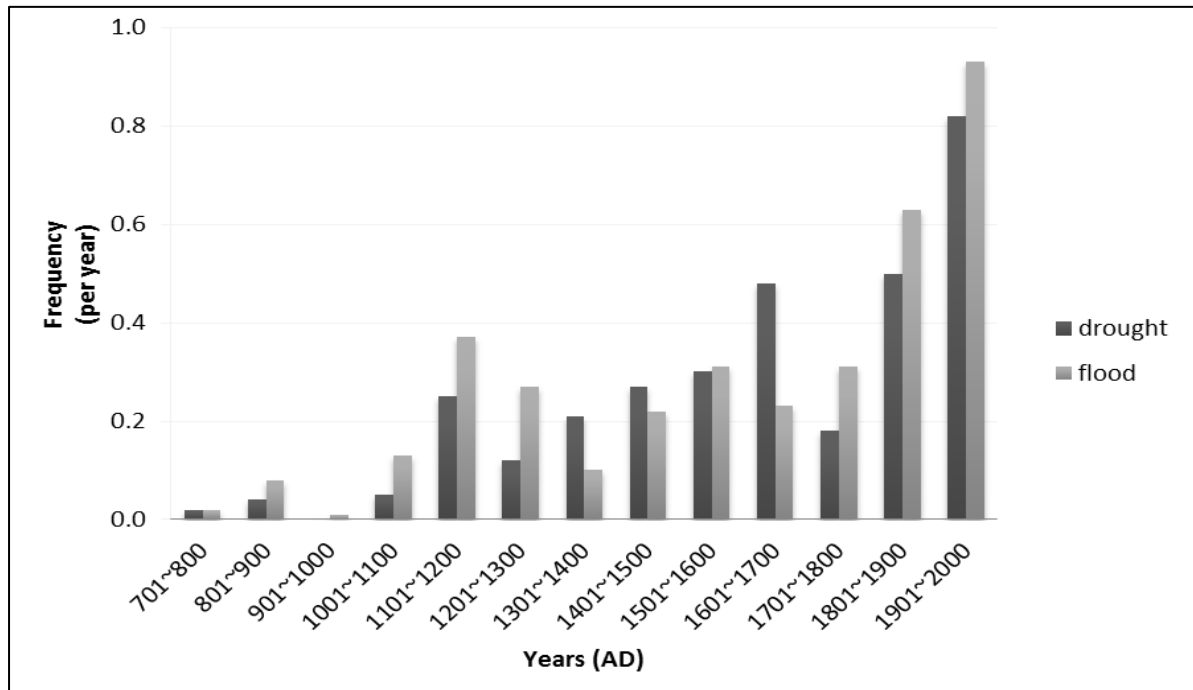


Fig. 8. The Frequency of Meteorological Records of Drought and Flood in Ningbo. *Source:* Plotted by Authors based on Data from Ningbo Meteorological Gazetteer (2001).

Table 1. Summary of the Administrative Areas of Ningbo City Government

Regions	Land Area (km²)	Residential Population (2010)*	Population Density (persons/km²)	Town *	Township **
Urban District	2,461.76	3,491,597	1418	78	11
Haishu	29.38	373,742	12721	22	2
Jiangdong	33.75	366,648	10864	0	0
Jiangbei	208.16	361,242	1735	1	0
Beilun	599.03	612,267	1022	2	1
Zhenhai	245.9	418,500	1702	2	0
Yinzhou	1,345.54	1,359,198	1010	17	1
County	7,354.47	4,114,092	559	56	9
Xiangshan	1,382.18	503,279	364	10	5
Ninghai	1,843.26	646,074	351	11	3
Yuyao	1,500.80	1,010,659	673	14	1
Cixi	1,360.63	1,462,383	1075	15	0
Fenghua	1,267.60	491,697	388	6	0

*Bureau of Statistics of Ningbo, 2011; **Bureau of Statistics of Ningbo, 2010

Table 2 Historic flood events, previous typhoon and rainstorms Ningbo of the last two decades

Date	Types of flooding	Typhoon events	Precipitation(mm/24hr)	Socio-economic impacts	Citations
2013.10.13	Pluvial, coastal and surface water flooding	Typhoon "Fitow"	<ul style="list-style-type: none"> ▪ Yuyao district: 248.2mm/24hrs; ▪ Fenghua district: 330mm/24hr ▪ Yinzhou district: 418mm/24hr (The highest record since 1949); ▪ Jiangbei district: 384mm/24hr (flooded area: 80% of Jiangbei district). 	<ul style="list-style-type: none"> ▪ The event caused by storm surge (raising tidal level) and intensive rainfall (acute intensive discharge) at 1-in-100 years return period event; ▪ Direct economic losses of whole Ningbo: 33.3 billion RMB in total; ▪ Flooded-hit population: 2.48 million; ▪ Yuyao, Fenghua, Jiangbei and Yinzhou were inundated severely compares to other districts (e.g.70% of roads in Yuyao were flooded); 70% of main urban areas flooded; ▪ Other districts (Ninghai, Xiangshan, Zhenhai and Beilun) were also inundated. 	Pan et al. 2013
2012. 8. 1-10	Pluvial and surface water flooding	Typhoon "HAIKUI"	<ul style="list-style-type: none"> ▪ Rainfall in the whole process was more than 500mm in 10 days 	<ul style="list-style-type: none"> ▪ This flood event caused by the intensive rainstorm; Fenghua, Yinzhou, and Jiangbei districts were inundated; ▪ Floodwater retained for 7 days in these districts; ▪ Flooded-hit population: 1.432 million; direct economic losses of whole Ningbo: 5 billion RMB in total. 	Bian and Hu 2012; Li and Hu 2012
2011.8.8	Pluvial and flash flooding	Typhoon "Meihua"	<ul style="list-style-type: none"> ▪ Rainfall was (> 200mm/24hrs) recorded at Siming Mountain station (West of Ningbo) 	<ul style="list-style-type: none"> ▪ Direct economic losses of whole Ningbo: 1.87 billion RMB (Agriculture: 0.86 billion RMB, industry and transportation:0.73 billion RMB); ▪ Severe flooding occurred in Yinzhou and Yinjiang districts; 	Yin 2011
2009.8.2	Pluvial flooding	Intensive rainstorm	<ul style="list-style-type: none"> ▪ The intensive rainfall period was was in between 10:00-18:00 (248mm/8hr) 	<ul style="list-style-type: none"> ▪ Many houses, roads and water infrastructures were damaged in the west of Yinzhou district. 	Ningbo Municipal Water Conservancy Bureau, 2010
2009.8.9	Pluvial and surface water flooding	Typhoon "Morakot"	<ul style="list-style-type: none"> ▪ Dacai Station of Ninghai had a highest rainfall of 176mm/24hrs; Fenghua: 169mm/24hrs; Ninghai: 114.3mm/24hrs; Xiangshan: 75 mm/24hrs; Yuyao: 65 mm/24hrs; Yinzhou: 51 mm/24hrs 	<ul style="list-style-type: none"> ▪ 295 houses collapsed; 400 thousands of people suffered from this typhoon across 11 districts of Ningbo; ▪ Direct economic loss of 1 billion yuan, (0.525 billion RMB was for agriculture, 0.221 billion RMB was for transport and industry, 0.191billion RMB was for water infrastructures) in the whole city; ▪ Yaojiang, Fenghuajiang and Nuoxi were the most flooded areas. 	Ningbo Municipal Water Conservancy Bureau 2010
2007.10.8	Pluvial flooding	Typhoon " Luosha"	<ul style="list-style-type: none"> ▪ The rainfall of Dacai Station in Ninghai was 172mm/24hrs. 	<ul style="list-style-type: none"> ▪ Ninghai, Northwest of Fenghua and urban centre were flooded seriously in Ningbo; ▪ Up to 7th October 2007, the inundated agriculture land were 22.3 thousands hectares. 	Ningbo Municipal Water Conservancy Bureau 2009; Cao 2007

Date (cont.)	Types of flooding	Typhoon events	Precipitation(mm/24hr) and river alert levels	Socio-economic impacts	Citations
2004.9.13-14	Pluvial and surface water flooding	Typhoon "Haima"	<ul style="list-style-type: none"> ▪ Fenghua: 183(mm/24hr); Ninghai: 135(mm/24hr); Beilun: 128(mm/24hr) ▪ Urban area of Ningbo: 116(mm/24hr) 	<ul style="list-style-type: none"> ▪ Flooding occurred in the low-lying areas in Ningbo (i.e. Yinzhou, Fenghua, Yuyao, Beilun); ▪ Xiajialing of Yuyao had suffered a destroyed mudslide in the early morning of 13 September; Collapsed houses: 121; Flooded crops 437 hectares; direct economic losses of whole Ningbo: 300 million RMB (at 2004's rate); The rainfall of the whole was mainly on Fenghua, Ninghai, Beilun, Putuo, Shipu districts and the city centre of Ningbo. 	Meteorological Bureau of Zhejiang Province 2005
2000.8.10-11	Pluvial and surface water flooding	Typhoon "Jielahua"	<ul style="list-style-type: none"> ▪ Rainfall of Sanmen Station in Ningbo was 207(mm/24hrs). 	<ul style="list-style-type: none"> ▪ Ningbo and Zhoushan were the places with most serious floods. Xiangshan was the most flooded in Ningbo; 75 towns suffered from this flood in Ningbo; ▪ Collapsed houses in Ningbo: 1516; flooded crops: 28 thousand hectares; direct economic losses of whole Ningbo: 330 million RMB. 	Zhejiang Water Conservancy Bureau 2000 ; Yu 2000
1997.8.17-18	Pluvial and surface water flooding	Typhoon "Winnie"	<ul style="list-style-type: none"> ▪ Ninghai was one of the flooded areas with rainfall of 325 (mm/24hr). 	<ul style="list-style-type: none"> ▪ 80% of Ningbo was flooded; direct economic losses of whole Ningbo: 4500 million RMB (at 1997s rate); collapsed houses: 26000. 	Ningbo Daily 2012