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Chapter 9
Exploring Spatial Relationships in the Pearl River Delta

Liang Xiong and Steffen Nijhuis

9.1 Introduction

Urban deltas belong to the most promising regions considering their population concentrations, ecosystems service and economy significance. Meanwhile these regions are facing multiple threats and are extreme vulnerable for increasing flood risk, damage of social and ecological values and substantial economic losses. These challenges are demanding a fundamental review of the planning and design of urban delta landscapes and infrastructures, in particular in relation to environmental issues and sustainability. Systematic study of urbanized delta landscapes is essential as a basis for future-oriented action and thinking for the sustainable development of these rapidly changing landscapes (Meyer and Nijhuis 2016). Key in this perspective is to understand urbanizing delta landscapes as complex systems composed of subsystems, each with their own dynamics and speed of change (Meyer and Nijhuis 2013; Dammers et al. 2014; Meyer and Nijhuis 2016). As a system the urbanized delta landscape is a material space that is structured as a constellation of networks and locations with multiple levels of organization at different spatial and temporal dimensions. Mapping the peculiar form of these systems provides insight into the complexity of the built environment and the related spatial networks—and with that, understanding in important social and ecological relationships. Insight into the morphology of the natural landscape, networks and urban pattern provides not only a window to the complex tangible relationships between them, but offers also important clues to get a grip on intangible relationships and driving forces, such as social networks, knowledge exchange, governance structure, tax systems

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etc., that shape the urban landscape. Urban delta landscapes as such can be defined as an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors (cf. Council of Europe 2000).

This chapter aims to introduce a multiscale mapping approach to understand and represent urbanizing delta landscapes while addressing different spatial and temporal dimensions of the involved natural and urban systems, and their roots in social network changes. Subject of this study is the Pearl River Delta (PRD), one of the quickest and most densified large scale urbanizing deltas of the world for the past four decades, to gain insights in the spatial mechanism of urbanization in deltaic circumstances and the problems it causes. It will serve as a case study to exemplify how mapping can be used for constructing and communicating knowledge on tangible and intangible aspects as a basis for sustainable urban regional urban landscape design and planning throughout the scales.

The first section elaborates on the theoretical and methodical backgrounds of the study. Next the PRD is introduced, followed by a cartographic exploration of the landscape, networks and urban patterns in the PRD. The chapter closes with a discussion of the findings and conclusions.

9.2 Theoretical Framework

9.2.1 Urbanized Delta Landscapes as Systems

The urbanized delta landscape can be regarded as a result of both natural and artificial processes (Meyer and Nijhuis 2016). In this perspective the urban landscape is considered a system where different processes and systems influence each other and have a different dynamic of change (Braudel 1966). The landscape is thus a mediator between nature and society, based on a material space that exists as a structure as well as a social and ecological system, which is independent of perception; landscape is a level of organisation of systems (Burel and Baudry 2003).

Systems are organised entities that are composed of elements and their interaction, and consist of structures and processes (Batty 2013). The urban delta as system is a constellation of networks and locations with multiple levels of organisation (Doxiadis 1968; Otto 2011). Networks are important for social and ecological interactions, communications and relationships. Locations are the result of the synthesis of interactions. The networks can be defined as the formal expression of structures for the (1) provision of food, energy, and fresh water; (2) support for transportation, production, nutrient cycling; (3) social services such as recreation, health, arts; and (4) regulation of climate, floods and waste water. Locations are the spatial expression of a locale whose form, function, and meaning are a result of social, ecological and economical processes (Nijhuis and Jauslin 2015).

Though the relationship between networks and locations is not pre-determined in its outcome, networks are becoming more dominant as a spatial manifestation of power and function in society (Castells 2000). This shift implies that design disciplines should not only focus on locations but also on the networks because they have the potential to gain operative force in territorial transformation processes (Nijhuis and Jauslin 2015).

9.2.2 Mapping Urbanized Deltas

Mapping serves as an important tool for the systematic study of urbanized delta landscape in knowledge generating, visualizing, experimental design and decision making. It is a means to generate knowledge from the complex interactions and networks. Maps as a product and the process of mapping are both important means for visual thinking and visual communication in order to understand delta landscapes. Maps help us to reflect upon emerging insights, appraise the landscape in its totality, and observe the relationships between the parts and the whole (Nijhuis and Pouderoijen 2014).

Map dissection and map comparison are useful analytical operations in order to understand urban delta landscapes as systems. Map dissection is about discovering spatial patterns by selection and reduction, and often serves as the basis for spatial association analysis, which explores the relation between different patterns. Techniques for spatial association analysis are overlay analysis and cross-reference mapping. Overlay analysis is employed to derive relationships by applying thematic overlays to geographic location. Map comparison is about finding similarities and dissimilarities in space, time, and theme between the different urbanized deltas, as well as within the individual delta. Since spatial dynamics and changes over time are hard to express in a static map, different time-slice snapshots need to be mapped in order to delineate the development of a delta landscape (Nijhuis and Pouderoijen 2014).

9.2.3 Spatial and Temporal Scale

From the systems perspective, the urbanized delta landscapes comprises of functions with spatial and temporal dimensions (Nijhuis and Pouderoijen 2014). In order to comprehend the heterogeneity of this composition in space and time should be viewed as a scale-continuum (Nijhuis 2013). Therefore, temporal and spatial scale is essential to understand the dynamic of a system, its elements and interaction with other systems and implies that a particular location is always part of the larger context. Spatial scale is related to grain, resolution and extent (De Jong 2012). Grain refers to the finest resolution of a phenomenon or a data set in space or time within which homogeneity is assumed, while extent refers to the expanse in space or time of a study (Turner et al. 1989). Temporal scale refers to the dynamics of development and change in time. Natural landscapes take much longer to develop than infrastructure networks and urban extensions.

Through mapping different spatial and temporal scale urbanized deltas can be explored by changing one of the three parameters: grain, extent and resolution. This offers possibilities to link the different scale levels and to consider the urban delta landscape as a scale-continuum (see Figs. 9.1 and 9.2). By studying the scale change, different systems and elements within them are possible to be composed, linked and understood under the same temporal and spatial scale.

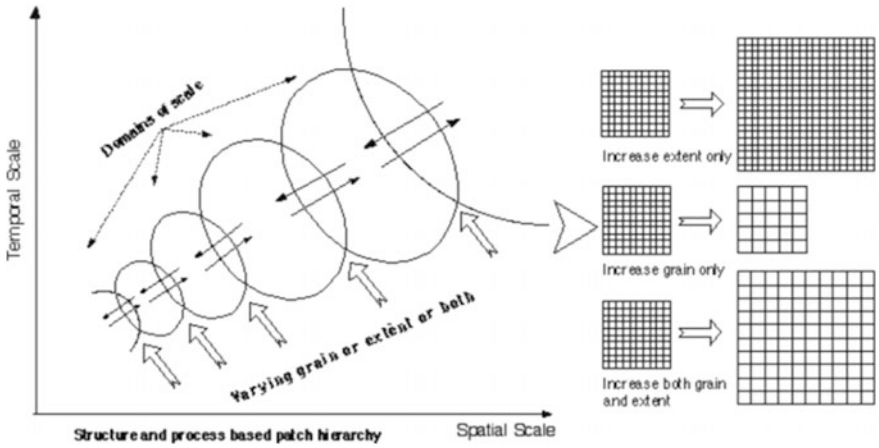

Fig. 9.1 The three ways of information scaling in a temporal—spatial scale system: extent scaling, grain scaling and resolution scaling (Wu 1999)

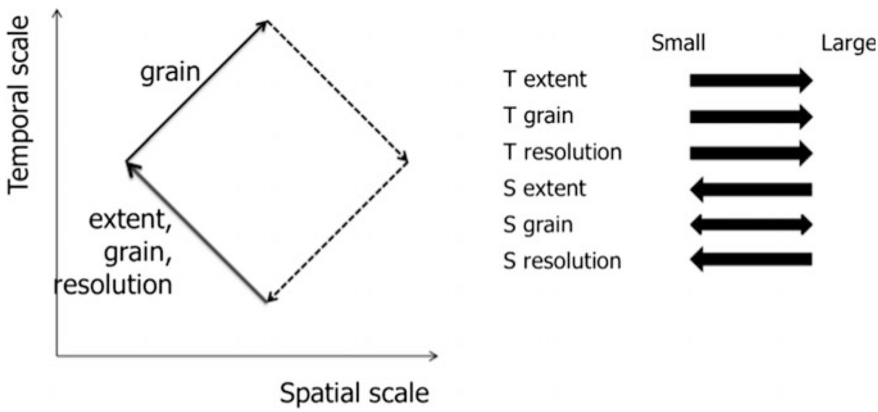

Fig. 9.2 The spatial and temporal scaling possibilities in the cartographic exploration of urbanized deltas. The temporal extent, grain, and resolution can be scaling upwards; the spatial extent and resolution can be scaling downwards; while the spatial grain can be scaling both upwards and downwards

9.3 PRD as a Case Study

9.3.1 Introduction to PRD

Being the quickest developing and most densified urbanizing deltas in the world for the past four decades, the PRD has surpassed Tokyo to be the world's largest urban area in both size and population in 2014 (World Bank 2015). This area has lead the Chinese urbanization and socioeconomic transformation with ground breaking changes since 1980s (Lo 1989; Yeh and Li 1999). Speaking of the speed, its GDP has increased more than 400 folds from 1980 to 2013 (see Table 9.1), while the population rocketed from 20.1 million to 47.9 million between 1982 and 2000 (Tang 2008). The PRD has also ranked as one of the most quickly developing regions in term of urban expansion (Wang et al. 2012). The built-up area emerged at an average speed of 82.1 km^2/year between 1989 and 1997 (Weng 2002). Urban areas have increased by more than 300% between 1988 and 1996 (Seto et al. 2002). Considering the size, Over 56 million permanent residents lives in the delta area (Li 2011), including the world's two urban agglomerations with highest population growth since 1970 (United Nations 2012). Besides the quick developing urban system, the PRD is the most diverse delta in water ecosystem of China. With 383 Phytoplankton species, 410 Zooplankton species and more than 450 fish species, the Pearl River ranks first in the freshwater biodiversity of China (Cui et al. 2005; Wang et al. 2013).

The delta can be divided into two parts with different types of geomorphology. A strong fluvial-dominated characteristic showed in its main part, while tide-dominated characteristic were mainly recognized in the east wing (Li et al. 2001). 80.6% of the land in the delta is flat terrain with about 160 hills and 187 islands spreading around the coast (Huang and Zhang 2004). It starts from the joined point of *Xijiang* (West River) and *Beijiang* (North River) in *Sansui* (Three Rivers), and Shilong in the *Dongjiang* (East River). These three major tributaries (see Fig. 9.3) have contributed the drainage area of the Pearl River in 77.8, 10.5, and 6.6% respectively (Chen et al. 2010), and the sediments of 86.9, 6.2 and 3.7% (Liu et al. 1998). 20% of the sediments settled inside the delta and the rest spread around the estuaries (Wang et al. 2005). The Pearl River is the second largest river in terms of stream flow in China after Yangtze River featuring a drainage area of

Table 9.1 GDP growth in Pearl River Delta 1980–2013

Year	1980	1990	2000	2010	2013
GDP (Billion CNY)	0.12	0.87	7.37	37.39	53.06

Data from 1980–2000: (International Statistics Information Center of National Statistics Bureau 2009), 2010 & 2013: (Statistics Bureau of Guangdong Province and Survey Office of the National Bureau of Statistics in Guangdong 2011; Statistics Bureau of Guangdong Province and Survey Office of the National Bureau of Statistics in Guangdong 2014)

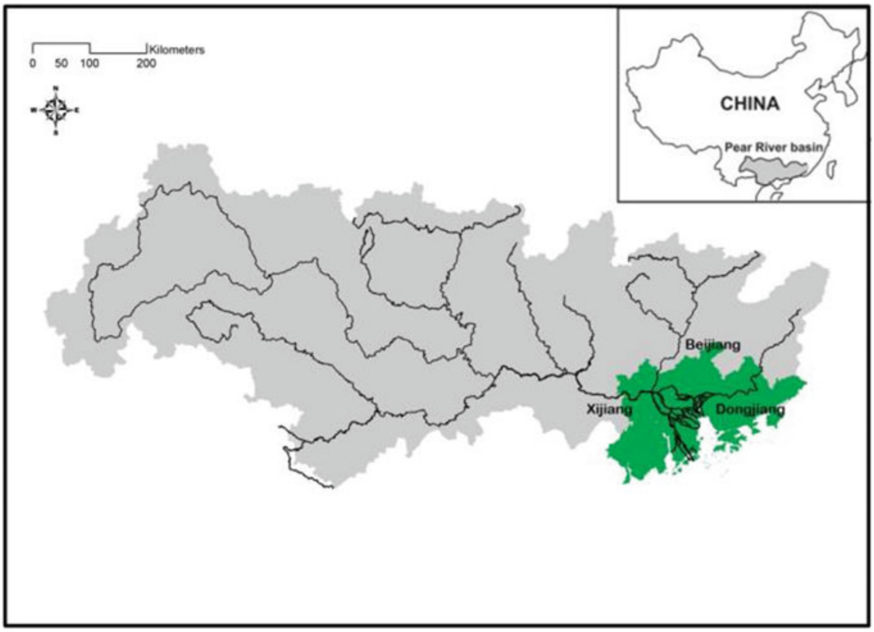

Fig. 9.3 Main tributaries in the Pearl River Basin and the PRD. The delta landscape is complex because of river network formed by the three main rivers Xijiang, Beijiang and Dongjiang, which joined in the delta and formed eight estuaries (mapped by author)

453,690 km^2 and a length of 2200 km. 80% of the total stream flow of the river occurs in the flooding season from April to September (Zhang et al. 2008). Both the urban and natural systems are highly dynamic, while its challenges are in highly dynamic as well.

The 4000 years of extensive agriculture activities in the PRD have proved a sustainable human-environment relationship in this ever-changing wetland environment resulted from frequent flooding and continual seaward extension (Weng 2000). However, its sustainability is in doubt with the new circumstances. In 2016 the PRD could have faced massive floods due to the worst El Nino since the 1997/98 weather pattern, which lead to havoc flood of once in a hundred year, stated by the Pearl River Flood Control and Drought Relief Headquarters Office (Xinhua News Agency 2016). Besides flood, the delta also suffered from the threat such as mangrove disappearance (Zhao 2010), saline (Xu and Luo 2005), agriculture land loss (Hu et al. 2002; Hu and He 2003), air and water pollution (Chau and Jiang 2003; Ouyang et al. 2006), water shortage (Li 1998; Chen and Chen 2004), and decreasing social security (Huang 2003). Despite the increasing awareness of the necessary of integral planning and design approaches, there is evidence that the potential of such approaches has not been fully exploited in urban landscape development. An attempts of the sponge city planning, one of the latest integration initiative of storm water management promoted by the national government, usually found stuck in approaching two to four plans made by different sectors (Che 2016). Such sectoral segregation blocks the integral planning (Yu 2016). Therefore, the lack of knowledge of framework and approaches in integral planning appears to be a significant barrier preventing a sustainable and adaptive urban landscape development in PRD.

9.3.2 Data Availability

The main data used in this study is the morphological information deriving from the delta's natural and human dynamic. The studied time period covers from 4000 BC to 2016 AD, in which all the major natural and human dynamic of PRD involved until recently. On one hand, sedimentation, river channel change and coastal line development are considered to be the major natural dynamic. On the other hand, dike construction, land reclamation, farming, fishpond construction, main road construction, and settlement development has been identified as the major human dynamic. The morphological data are collected from geological studies, historical maps, master plans, archives and GPS assisted field trips (Table 9.2). All data are converted into digital form, rectified with projection of WGS84 with Google map as base map. The data then has been organized with the help of software environment in ArcGIS 10 and Illustrator CS 6.

We apply two steps of data validation, both accountability and validity, towards the morphological data. The accountability of the data has been validated by comparing maps of different sources, while the validity check has been done by other types of data. We deployed both visual and metadata check to evaluate the accountability of the maps during the digitalization process (evaluating map quality, coordination system, time frame, and resolution). In the validity check process,

Table 9.2 Morphological data acquiring time range and sources

Time range	Type of sources	Sources
4000 BC–1980 AD	Geological studies	Zeng et al. (1982), Zeng and Huang (1987) and Li et al. (1991)
600 AD–1950 AD	Historical maps	U.S. Army Map Service (1954), Tan (1982) and Guangdong Historical Atlas Board (1995)
1900 AD–2000 AD	Archives	Board of Pearl River Delta Agriculture Gazetteer in Foshan Revolutionary Committee (1976), Feng (1990), Wu et al. (1990), Chen et al. (1995), Liu et al. (2001) and Mao (2002)
2000 AD–2015 AD	Master plans	Guangdong Provincial Department of Land and Resources (2009)
2010, 2011 and 2016 AD	Field trips	

we derived numeric and descriptive data from different sources of literature to verify the validity of the morphological data. After the two steps of check, the verified information has been sorted by time for exploration later.

9.4 Mapping the PRD

During the mapping exploration, we generate three set of maps based on the: landscape formation, water infrastructure network and urbanization. Nine temporal stages have been identified. According to the data availability, the maps of landscape can date back to 4000 BC, water infrastructure 1000 AD, and urbanization 1950 AD. Each set of maps are being studied separately, then their relationship has been linked.

9.4.1 Landscape, Networks and Urbanization

The maps of the natural landscape (see Fig. 9.4) indicate a series of speed acceleration in the delta formation process. There are three steps in the formation of the delta. The first change starts at around 1000 AD, second times from 1300 AD and the third times around 1950 AD. Because of such differences in change of speed, we adjusted the temporal scale for representation. Temporal grain has been changed from 2000 years to 1000 years since 1000 AD, and then from 1000 years to 300 years since 1300 AD, and finally refined into 50 years since 1950 AD.

We organized the maps of water infrastructure networks (see Fig. 9.5) based on the same temporal grains used in the maps of landscape. This series of map suggest the change of dike system. To be more specific, from 1000 AD to 1300 AD, only in the most dynamic section of the river the land owners did enforce the natural levee jointly to protect their farmland. Here also affected villagers cooperated in dike construction. Most dikes built at this time are semi open. From 1300 AD to 1600 AD, the local scaled dike system began to extend its length and height. Especially in the north of the delta region, the dike system started to link with each other and upscaling from local homogeneity to sub-regional homogeneity. From 1600 AD to 1900 AD, the dike system developed towards the newly formed part of the delta region in the south with the similar sub-regional spatial scale as it is in the last period. However, a huge change started since 1950 AD, when the dike system has been scaling up towards a regional level. Such spatial scaling resulted in an integrated regional dike system in 2015 AD.

Maps of urbanization (see Fig. 9.6) have also been arranged according to similar temporal grains. The two maps show the spatial development between 1950 AD and 2010 AD. Comparing to the former two sets of maps, we witnessed a far more

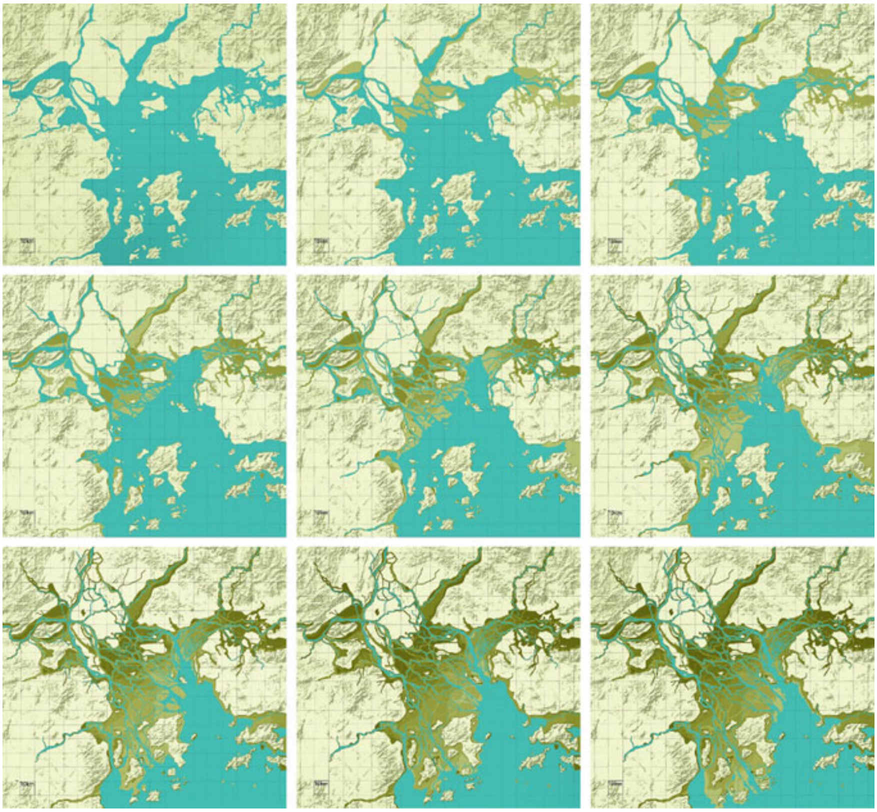

Fig. 9.4 Landscape series (4000 BC–2015 AD) featuring the landscape formation in 4000 BC, 2000 BC, 200 AD, 1000 AD, 1300 AD, 1600 AD, 1900 AD, 1950 AD, and 2015 AD

significant spatial change in a shorter temporal grain in the maps of urbanization. The maps in landscape, water infrastructure and urbanization reveal the spatial and temporal changes respectively. Insight of spatial mechanism is going to be discussed by linking and comparing these layers in the next section.

9.4.2 Link the Rhythms

After the completion of map series, we discover that the water infrastructure networks play an essential role in understanding of both the physical structure and social relationships in the delta. The dikes create important conditions for agricultural land-use and housing. By comparing the maps a change in the morphological co-relationship among three layers is visible. As indicated by the maps, the delta landscape is mainly formed by natural forces in the period from 4000 BC to

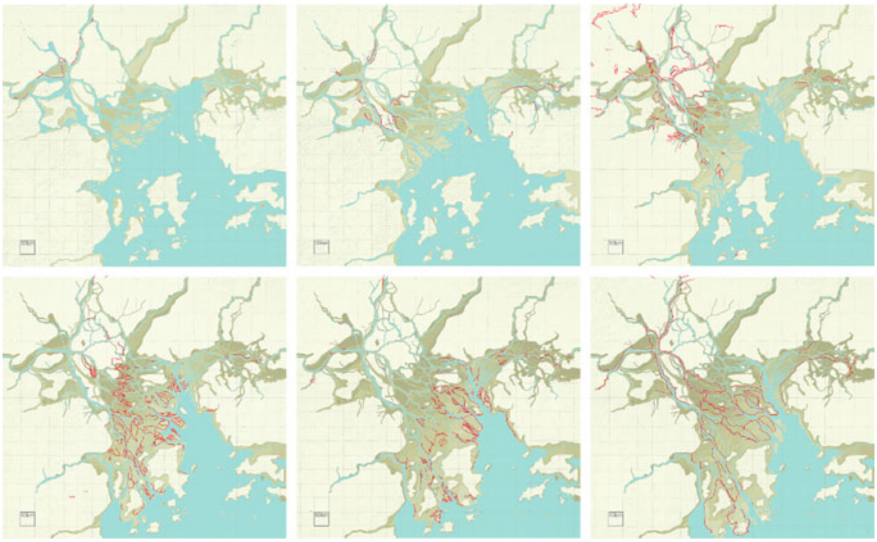

Fig. 9.5 Water infrastructure series (1000 AD–2015 AD) featuring the main dike morphology in 1000 AD, 1300 AD, 1600 AD, 1900 AD, 1950 AD, and 2015 AD

Fig. 9.6 Urbanization series (1950 AD–2015 AD) features the built up area in 1950 AD and 2015 AD

1600 AD. From 1600 onwards the dike system as important water infrastructure network exerted great influence on the formation of the land. The key to understand the territorial change is the social network that is related to the development of water infrastructure. Based on the availability of the maps and the literatures, we examined the social network changes in the period from 1950 AD to 2015 AD (see Fig. 9.7).

The number of dike rings shrink from over 1000 in the beginning of the 20th century to 218 in 1982 (Huang and Zhang 2004). The Nationalist Government of the Republic of China (ROC) started the large scale dike ring integration plan in PRD with the help of United State in 1928 (Archive Bureau of Guangdong Province 1928). Thirteen dike rings were identified as the most vulnerable. Integration and enhancement projects were planned. However, due to The Second

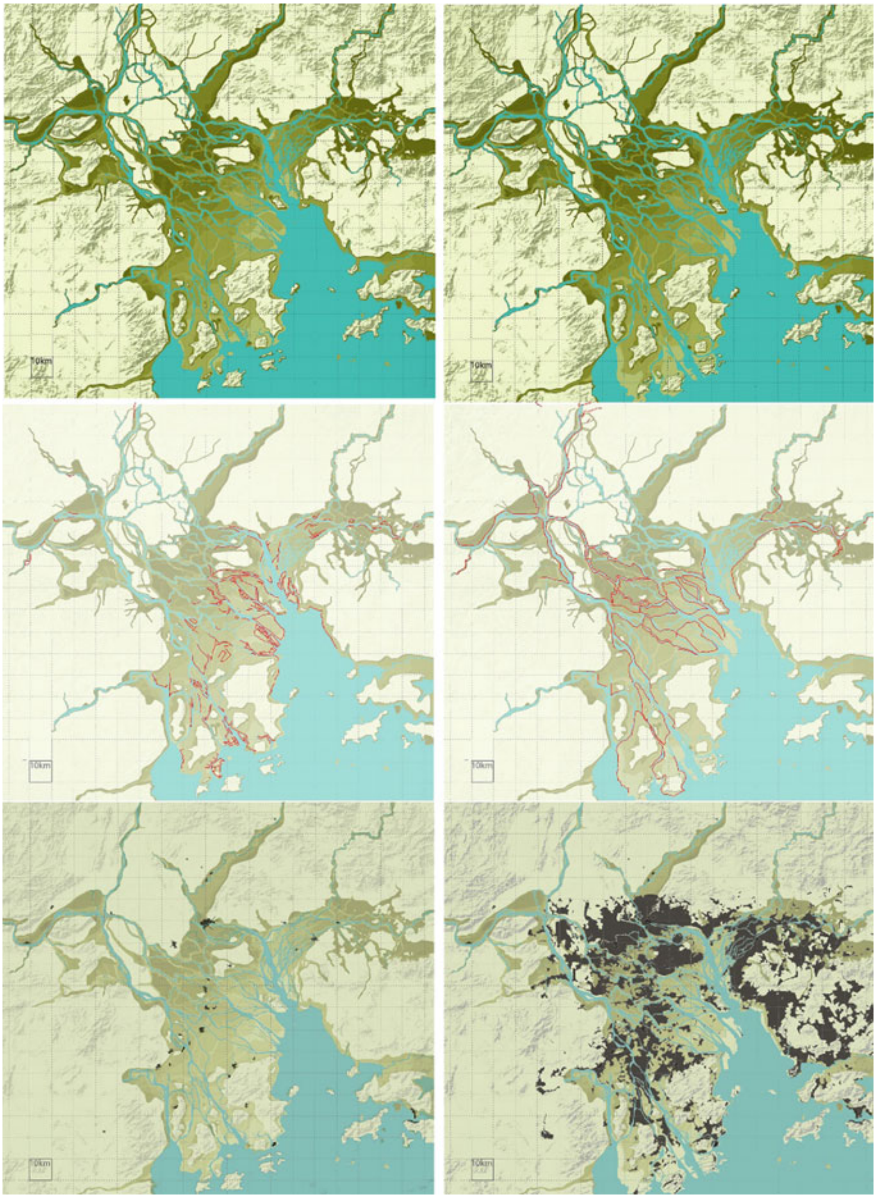

Fig. 9.7 Compare of maps between 1950 AD and 2015 AD in landscape, water infrastructure and urbanization

Sino-Japan War and Civil War from 1927 to 1950, the ROC government hardly had advanced to implement the plan before it was replaced by the Government of People's Republic of China (PRC) in 1949.

Since 1950, the change of land ownership from private to state owned has enabled the large scale infrastructure management in the delta. The integration of Dike system had significantly reduced the number of the dike rings from 2950 to 218 during 1949–1982 (Huang and Zhang 2004). Soon after the new government formed, two floods submerged an area of 3233 km^2 of farmland in the delta in 1947 and 1949 (Guangdong Province Planning Commission 1964). The Guangdong provincial government started the dike construction and integration project to control the flood and promote agriculture in the delta area. Before the project stared, there were 2950 dike rings. In 1961, the number of dike rings decreased to 530 with a total length of 3978 km. the dike rings protected population of 2.86 million farmland of 4160 km^2. Dike construction and management was no longer a Sub-region scale issue for villages or families. Instead, the Guangdong Province has taken the charge of the dike system management. The first application of this management switch is the large scale dike integration. This project aimed to shorten the length of dikes and to better protect the cities within the separated small and relatively weak dike rings. Small dikes are integrated into larger, higher dike rings. The dike systems in the Sub-region scale has been connected and upscaled into a more connected delta-scale dike system, which means better protection against flood. However, this upscale lead to a ignoring situation for long times. Besides enabling the cities originated from high lands and theirs suburban along the river a better protection against flood, the delta-scaled dike system also offered a much better protection for the farmland originated from reclaimed lowland. The hydrologic condition change among those farmland has enabled the fast rural urbanization without threatening from the flood.

Thanks to the delta-scaled dike system, a noticeable rural urbanization has had a better chance to spread throughout the Pearl River Delta in the reclaimed area since 1979. At this time the large scale dike system continued to grow with the process of downscaling of the urban system. The number of dike ring decreased from 218 to 53 in 2000 (Huang et al. 2000) During the urbanization, large areas inside the polders had been transfer from farmland into urbanized area. This means the tradition settlement pattern had switched. In the past, people lived in the high ground or elevated dike, using the polders for agriculture. Now they stepped down from the highlands to build cities on those lowlands, with the wish to use dike to protect all their belongings against water. The large-scaled dike system has hidden the flood threaten to most people: when they decided to convert their farmland into manufactory, and later when this manufactory became their main business, and finally all this individual business gathered into a new town. During the process, it is hard for the local citizen to realize their change in their farmland can lead to a totally change of urban pattern in the delta scale. It is an urban pattern that heavily dependent on the delta-scaled dike system, instead of the long tradition of landscape dependent in the Pearl River Delta. The local influence of the delta-scaled dike has changed the local recognition of the territory and their behavior, which lead to a more infrastructure-depended urbanization pattern in the delta scales. The current unawareness of the delta landscape has led to planning principles and approaches that are less likely to meet the increasing challenges of flood risk.

9.5 Discussion and Conclusion

The study shows that the multiple scales mapping approach can effectively address the different dynamics of the delta, especially in the need to understand the interaction among the tangible and intangible components of the delta system. Such exploration generates knowledge that helps to overcome the scale obstacle. In short, mapping is a helpful instrument for urban landscape study, especially in the study of urbanized deltas. We see the possibilities to generate more understanding from comparing more levels of spatial extent within each temporal stage. However, data acquisition becomes harder when we scale down in space and need high resolution data. We also found out that it is extremely hard to get valid morphological data of the past four decades urbanization. Possible reasons are (1) the national data security policy towards spatial information prohibits data acquisition from a foreign university, (2) sector segregation and local protectionism because of the governance among provincial and local governments, and (3) lack of awareness of the power of morphological knowledge sharing and exploration. Since such cartographic exploration can effectively organize, understand, analyze and design the different types of dynamic in urban region and its connected landscape, we plea for a more open data access and sharing from the authorities. Mapping activities would provide possibilities for better decision making and planning in the long run. Spatial information proofs to be important for decision makers and specialists from different disciplines to communicate effectively for urban landscape planning.

In PRD, three types of process are identified according to their speed: landscape formation, infrastructure extension and urbanization. We explained the spatial interaction from delta scale with a time extent ranging from two thousand years to fifty years employing the power of maps. We laid bare a transition from a water-based attitude to a land-based one, during which an unawareness of the underlying landscape and a detached urban pattern was developed. Such trends increased the flood risk in the new urban areas in the region at several scales.

The change of the social network plays an important role in shaping the physical environment in the PRD, especially in shaping the water infrastructure networks. The governance and available knowledge has led to an upscaling of the water infrastructure since 19th century. In turn this large scale water infrastructure shapes our knowledge and understanding of the delta into an unawareness of its increasing flood risk in the large scale. Such change results in a society with increasing dependence on the artificial flood defense system, in which an unlimited capacity could not be achieved. On the contrary, we see possibilities of a more sustainable future lies in the awareness of the flood risk in all levels of scale, and a more resilience physical structure of delta system. The mapping exploration in this study would serve well in constructing both the social awareness and the physical structure of the delta regions in this purpose.

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