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The interaction between port and delta: the case of Kaohsiung

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This research, taking Kao-Ping Delta as an example, focuses on exploring the relationship between port and delta. The goal is to clarify what are the crucial elements for delta transformation and how do they work. The complex relationship between artificial port city and natural delta will be illustrated by a layer-approach model of 3-Scale (delta, urban, and waterfront) and 3-Layer (occupation, infrastructure, and natural landscape) from the beginning of building Kaohsiung Port, about 100 years ago, to recent. It shows that the natural transformation of Kao-Ping plain had been artificially disturbed by the construction of Kaohsiung Port in the last century, which caused the change of water system and resulted in serious problems, e.g. coastal erosion, flood and land subsidence. Regional division of function is a major factor to drive the corresponding construction of infrastructure which profoundly affected the natural transformation of Kao-Ping Delta.

Keywords
Layer-approach; water system; delta; Kaohsiung Port; port city

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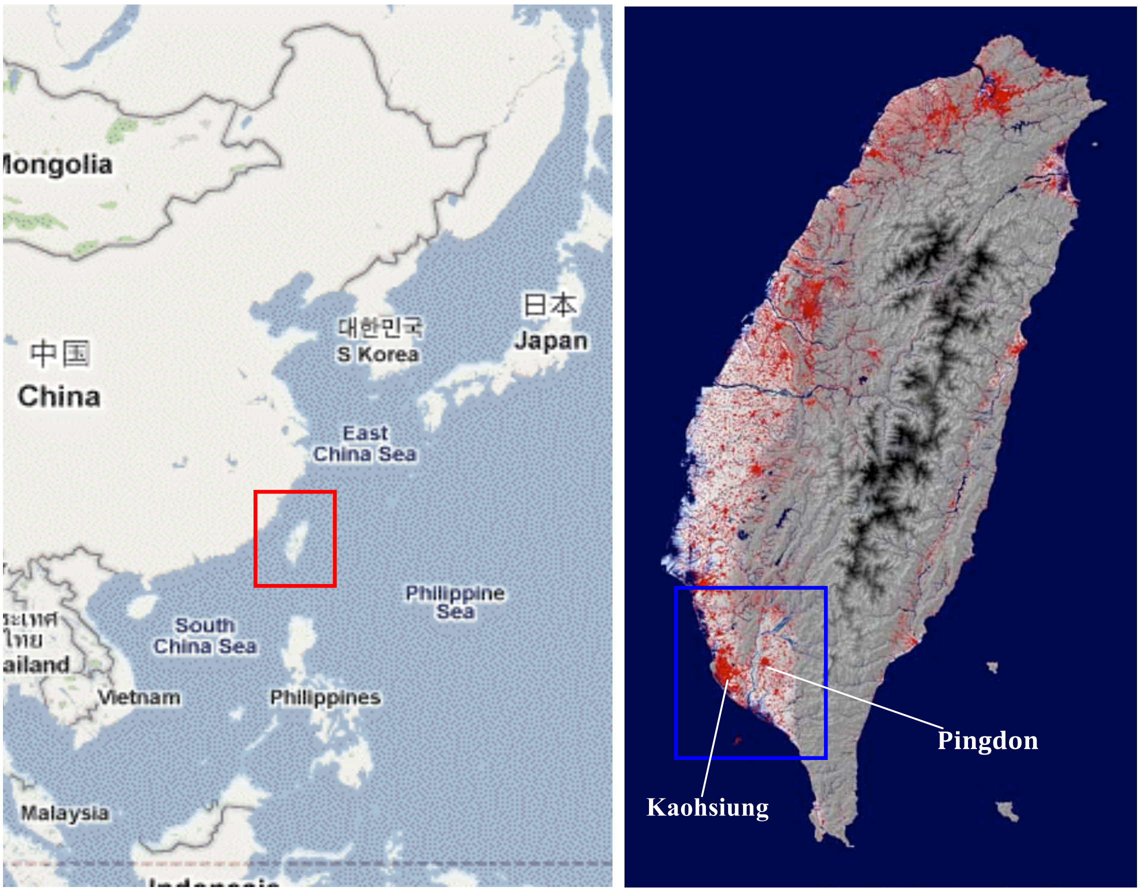
Introduction

Kao-Ping Delta is located in the south of Taiwan, a small island close to China and Japan. The strong tide from south to north spread huge amount of river sediment along the coast, which formed Kao-Ping Delta, including Kao-Ping Plain and Daku Bay (Kaohsiung port today). Kaohsiung and Pingdong are two important cities in Kao-Ping Delta. Kaohsiung with the main function of a port and Pingdong with the main function of distribution centre comprise the main spatial pattern of Kao-Ping Delta. The construction of Kaohsiung Port deeply affected the transformation of Kao-Ping Delta in the past century.

This article will introduce a model using a layer based approach to illustrate this complex interaction between the construction of port and the transformation of delta. The analysis framework comprises three main parts: (1) literature review of layer based approach and introducing the model of 3-Scale (delta, urban, and waterfront) and 3-Layer (occupation, infrastructure, and natural landscape); (2) phenomenon description on the perspective of 3*3 model, which tries to separately realize the transformation on three different layers; (3) deductive analysis to find out the relations between different phenomena and comprehensive interpretation to illustrate the mechanism of 3*3 model; and finally, this paper will end with conclusions and some suggestions to the development of Kao-Ping Delta in the future.

Figure 1. Left: location of Taiwan (Source: Google Map)
Right: location of Kao-Ping Delta in Taiwan



Literature review of layer based approach

Multi-layer Overlay Analysis

It was in the late 19th century when the concept of layer was introduced in Landscape. Olmsted, Lynn Miller and Charles Eliot in Pennsylvania State University, began systematically using hand-drawn, sieve-mapping overlays through sun prints produced on windows. After that, overlay technique gradually became a common tool, but a theoretical explanation was still lack (Ian L. McHarg and Frederick R. Steiner, 1998). An academic discussion of overlay technique did not appear until Jacqueline Tyrwhitt's work in 1950. In his book four maps (relief, hydrology, rock types and soil drainage) were drawn on transparent papers at same scale, and referenced to common control features. These data maps were then combined into one land characteristics map which provided a synthesis interpretation of the first four maps (Ian L. McHarg and Frederick R. Steiner, 1998).

McHarg refined these approaches and tried to provide a theoretical basis for overlaying information. His approach focused on both natural and artificial attributes in a given area and photographing them as individual transparent maps which were superimposed over each other to construct the necessary suitability maps for each land use. For example, in the study of Philadelphia metropolitan area, the physiographic region was divided into three components: uplands, piedmont and coastal plain which revealed the principal roles in the water relation. And then, he selected eight phenomena, including surface water, marshes, flood plains, aquifers, aquifer recharge areas, prime agricultural land, steep lands and forests and woodlands, for identification and examination. These x-ray-like maps displayed the proper land use: conservation, urbanization or recreation, which then were combined with others as overlays to produce comprehensive suitability map (Ian L. McHarg, 1969).

The model of layer based approach in the Netherlands

This systematic analysis was introduced into Dutch as the "Triplex model" which included three main layers: a-biotic, biotic and anthropogenic factors. A specific development on the triplex model was the "Framework Model" (Casco-concept) which viewed natural and artificial landscape as an integrated interaction system (Meyer & Nijhuis, 2011).

Layer approach became a popular concept-tool of planning in the Netherlands after 1998, when De Hoog, Sijmons en Verschuren suggest to distinguish three layers, substratum, networks and occupation, in the spatial organization of the Laagland (Lowland) (De Hoog, Sijmons and Versehuren, 1998). After the serious flood in 1995 and 97, this model provides a cohesion framework of spatial planning to re-consider the relationship between artificial and natural landscape in the future. When the concept had shifted from "fighting against the water" to "working together with water", layer approach provides a feasible way.

Although three-layer approach provides a broader vision to examine natural conditions, it still needs further improvement. The main question focuses on the complex interactions in/ between different layers. Namely, what is the mechanism of this 3-layer model needs to be further considered. A triple-3 layer model is developing in the Netherlands in order to solve this problem (Meyer & Nijhuis, 2011). Except the original 3-layer structure, this model adds three scales (river -catchment, delta-area and individual delta-city) and three periods (history, present and future) to analyze the transformation of delta.

*The model of 3-Scale * 3-Layer*

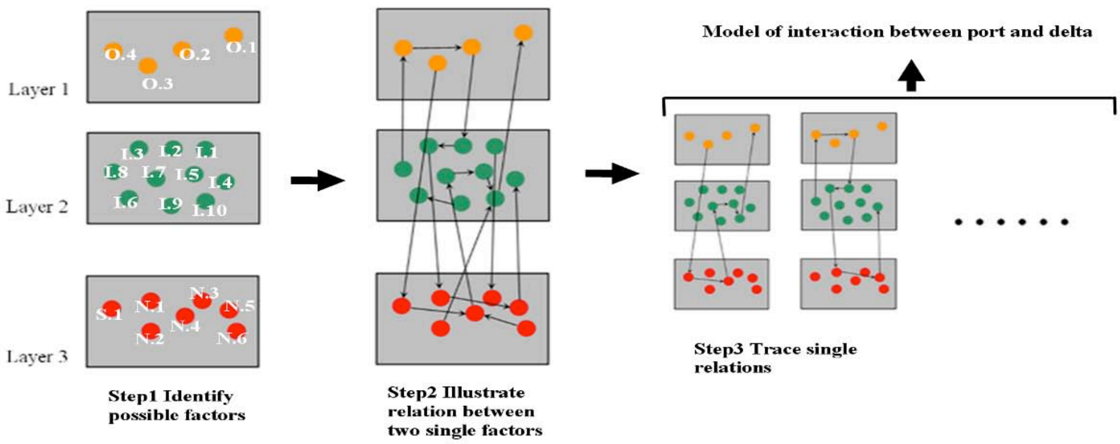
This research mainly deals with the question of interactions in/ between layers to support the deficiency of triple-3 layer approach. The issues of climate change will related to water texture in this research. In the case of Kao-Ping Delta, floods, coastal erosion, land subsidence and supplement of fresh water are urgent issues for adaptation of climate change. The analysis framework follows three main steps (Figure 2):

- The first step is to identify the whole possible factors in three layers based on literature. There are two main components in every layer: (1) spatial form and land use in occupation layer, (2) transportation and hydraulic system in Infrastructure layer, (3) soil composition and water system in natural landscape layer. Every component consists of several factors referring to the urgent issues for climate change.

- The second, by means of examining historical maps, statistics and literatures, the further relation between two single factors will be illustrated in either qualitative or quantitative way. The factors which several relations converge on will be the important points to be further examined.

- Finally, we can trace these single relations and find several deductive contexts. These contexts can be further organized a model of transformation between port and delta.

Figure 2. The concept of analyses framework



However, this research doesn't try to construct an ultimate model to exclusively interpret this context. The process of tracing relations tries to clarify the complex system and to find out new contexts rather than to purify and simplify the system. Namely, the best function of this model is to provide a foundation on which different disciplines can be organized by some proper issues.

Phenomenon description on the perspective of 3*3 model

Before the analysis of layer approach, it is quite necessary to input the related data into different layers respectively. The whole material will re-interpret by three layers, Occupation, infrastructure and natural landscape, which is helpful to further identify the possible factors in next step.

Layer of natural landscape

Substratum and water system are the two key elements in this layer. Substratum was mainly affected by river sedimentation in Kao-Ping plain. Kao-Ping River carries huge amount of sediment into the sea (Table 1). And then the strong tide around island pushing and eroding the sand shaped most of coastal plains. The original typology of Kao-Ping Delta could be found in historical map of Kaohsiung which will illustrate the main character of this delta (Figure 3). Huge amount of sand and stone was carried from mountain by storm surge every summer. The flow speed suddenly slowed down when river departed from mountain into plain. The slow flow resulted in the sedimentation of stone first, and then from gravel, sand to clay in weight order. The elevation map reveals the soil structure arranging in concentric circles that shaped the main terrain of Kao-Ping Plain. The layer with height from 5 to 5o meter is mainly comprised by gravel and stone (Figure 4). According to the history (長治□誌, 1990), the soil in this area was very poor keel. Gravel and stone spread all over this area after flood. Because the soil which is suitable for agriculture is loam, between sand, clay and silt, it can explain why the soil in this region was very poor keel.

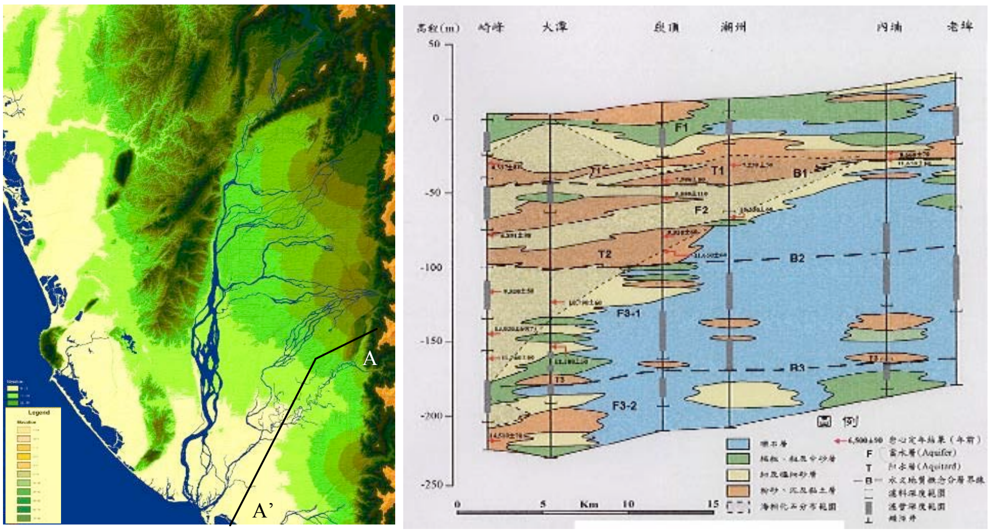
Because of the strong sedimentation in plain, the river bed with many sand bars inside is shallow and easy to clog. Once the river bed was silted up, water would find new ways to flow, which made a dendritic net of channel. The terrain of plain is high in north and low in south. This physical character of terrain resulted in many branches with flow direction from east to west-southwest arranged in order from north to south. Due to the special substratum, the area where channels just departure mountain, with merely height from 5 to 50 meter, is the main discharge area. Water is easily absorbed by soil in this area, which results in abundant ground water system beneath the plain. Once rocks or dense clay blocks the water way, it will change its way or gush out as springs.

Figure 3. Historic map of Kaohsiung in around 300 years ago (Source: 乾隆輿圖), huge sediments being carried by strong tide spread along north coast of river mouse and formed a natural bay

Table 1. Quantitative comparison of Mississippi (Americas), Rhine (Europe) and Kao-Ping River (Sources: Meyer & Nijhuis, 2011; The committee of Kao-Ping River Basin, 2008)

	Mississippi	**Rhine**	**Kao-Ping**
Length	6,275 km	1,320 km	171 km
Depth-average	New Orleans: 60 m	Arnhem: 8 m	
Discharge-average	16,000 m3/s	2000(summer)m3/s	250 m3/s
Discharge-extreme	48,000 m3/s	12,000m3/s	29,100 m3/s
Sediment transport	170 million ton/yr	0.4 million ton/yr	35.6 million ton/yr
Sediment-average	0.337 kg/m3	0.0063 kg/m3	4.5 kg/m3

Figure 4. Elevation of Kao-Ping Delta 100 years ago (Original data: Academia Sinica) and Ground section of delta (Source: Water Resources Agency, 2000)



Layer of infrastructure

Hydrologic system was the most important infrastructure before colonial age for agricultural usage. Because of the separated surface water system, different hydrologic infrastructure was needed in Kaohsiung and Pingdon, the forward one was lack and the other excess of water resource. Tsoa-Kon-Zwin (曹公□) Irrigation in 1839 in Kaohsiung and Tson-Chi dike (昌基堤防) in 1902 in Pingdon respectively resolve different water problems and facilitated the agricultural development in these two areas.

The obviously functional division of Kao-Ping delta began in colonial age. Japan Empire constructed Kaohsiung Port as a substantial rear base for invading south Asia. About 1.5% of world sugar output was contributed by Taiwan in 1910. That is why Japanese viewed Taiwan as a base to support their military needs in Asia. Transportation became the priority infrastructure in order to transfer agricultural products to port.

Following the regional division, Agriculture was pushed toward the east by the development of port. The original irrigation, Tsoa-Kon-Zwin, lost its crucial role. The new irrigation channel built in 1933 and 1949 revealed the new agricultural development (Figure 5).

Figure 5. The phases of construction of Tsoa-Kon-Zwin (Original data: Web of Tsoa-Kon-Zwin, Council for Cultural Affairs of Taiwan)

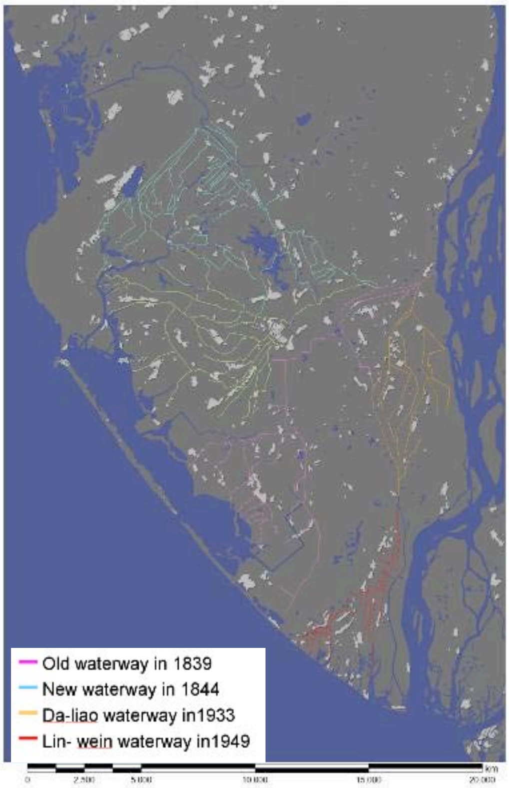
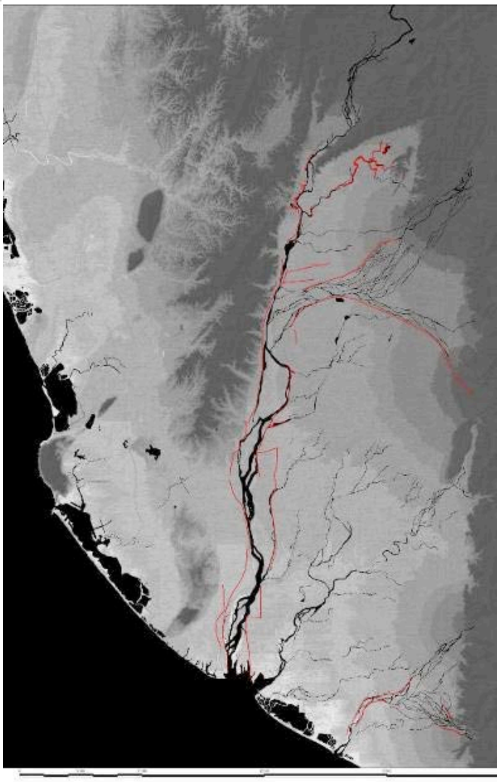


Figure 6. New dike system of Kao-Ping Delta in 1938 (Original data: Elevation map of Taiwan by Japan, Academia Sinica)



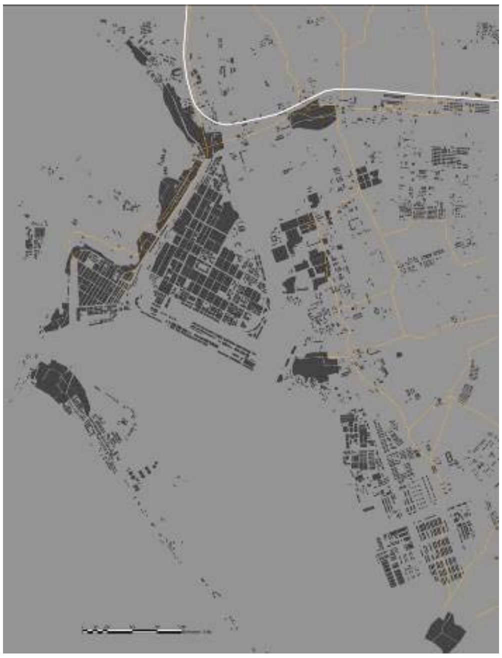
On the contrary, farming was supported by Japan in Pingdon Plain. Although there was poor keel soil in northern delta, sugarcane which was of the character of drought enduring was quiet suitable for this kind of soil. How to resolve the problem of frequency flood was the priority in this area. In 1929, the hydraulic construction began to build a long dike on the south bank of this creek from the location where it departure mountain. This dike was finished in 1938, which forced water to flow toward north-west through Ian-Pu (鹽□), Li-Gun (里港) to main stream of Kao-Ping River (Figure 6). The huge amount of original creek mudflat gradually became farm (陳正祥, 1998). Most of which became sugarcane-farm.

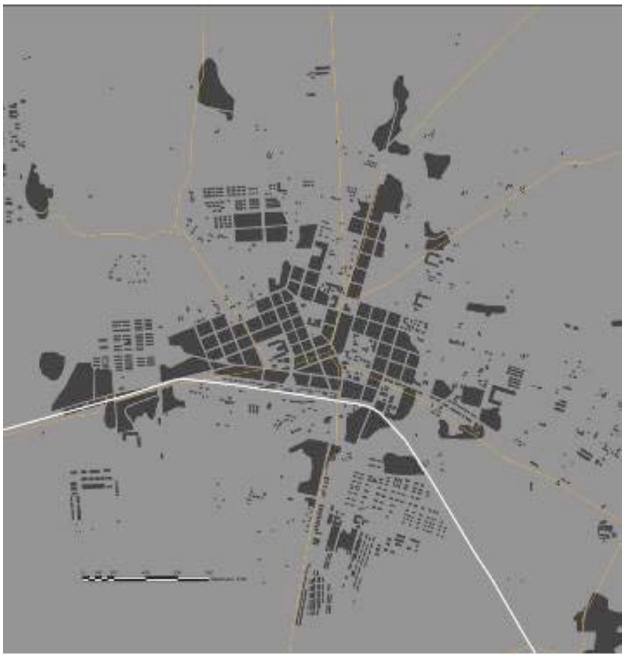
Layer of Occupation

Following the regional division in colonial age, Kaohsiung and Pingdong were functionally integrated together. The former transformed into port city and latter became a collective centre of agricultural products. The new transformations of spatial patterns in these two areas were different from the previous patterns. In colonial age, the construction of port facilitated regional division. The regional centers shifted from Zoin and Phonshan, as original authority centers, to Kaohsiung and Pingdong, as a port and a distributing center. Urban grid system was introduced into these two cities by Japanese, which developed mainly along infrastructure forming the main characters of these two cities (Figure 7, 8). The Nationalist Party (KMT) took over Taiwan after War World II and basically inherited Japanese concept to develop Kaohsiung. Moreover, there were more and more industrial parks and export processing zones being set up Koahsiung in the 1970s. KMT government regarded Koahsiung as the industrial center of Taiwan.

Figure 7. Grid system along the direction of port in Kaohsiung (Original data: Elevation map of Taiwan by Japan, preserved by Academia Sinica)

Figure 8. Grid system in different directions along different directions of roads converged at the center of Pingdong (Original data: Elevation map of Taiwan by Japan, preserved by Academia Sinica)





Deductive analysis to clarify the relations between different phenomena

Based on the description of three layers, we divide every layer into two main contents which comprises several analysis factors respectively. Each factor will be examined how they affect, qualitatively or quantitatively, other factors (Table 2).

Table 2. Factors in different layers

LAYER	CONTENT	FACTOR	EFFECTED By	Related quantitative qualitative
Occupation	Form	O.1 Organization Patterns	O.4	Ratio of public space
			I.6 / I.7	Location
			N.5	Location
		O.2 Building type	O.3 / O.4	
			N.1	
	Land use	O.3 Density	O.4	Ratio of building floor
		O.4 Division	I.3 / I.4	Ratio of land use
			N.5	Location
Infrastructure	Transportation	I.1 Road / Street	O.4	Net structure
			I.5 / I.6	Length and width
		I.2 Railroad	O.4	Location
		I.3 Port	S.1	Flow and Sediment
		I.4 Airport	--	
	Hydraulic system	I.5 Dike / Levee	N.3	Flow
		I.6 Canal	I.3	Length and width
		I.7 Dam	N.3	Location
		I.8 Irrigation	O.4	Length and superficies
		I.9 Draining: rainfall and waste	O.1 / O.2 / O.3	Length and flow amount
			I.1 / I.6 / I.7	Location
		I.10 Drinking water	O.1	Location
			O.3 / N.3 / N.5	Water amount
Natural landscape	Soil layer	S.1 Sedimentation	N.3	
	Water system	N.1 Precipitation	--	
		N.2 Runoff	O.1 / O.2 / O.3	Water amount
			I.1	Direction
		N.3 Discharge (river)	I.5 / I.6 / I.7 /I.9	Water amount
		N.4 Recharge (Infiltration)	O.3	Water amount
		N.5 Percolation	N.4	Water amount
		N.6 Transpiration	--	
		N.7 Evaporation	--	

(N.3 - S.1)From the beginning: A natural bay for port

Huge sediment which was carried by Kao-Ping River accumulated at river mouse. The strong tide brought the sediment from south to north spreading along coast, which formed Da-Gou Bay, the ancient name of Kaohsiung.

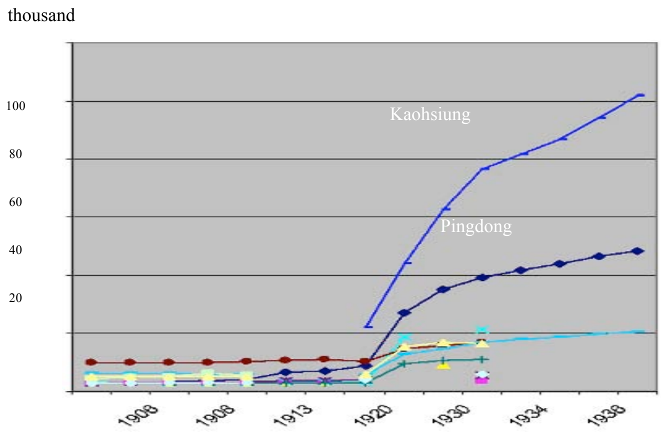
(S.1 - I.3) process of port construction

There were two surveys of Koahsiung made by Japanese in 1899 and 1905. They analyzed the situation of resources and transportation, compared Kaohsiung with more than six other ports of Taiwan (高雄市志, 卷九交通志), and finally made the plan to construct Kaohsiung port.

(I.3 - O.4) the construction of port to regional division

Since 1908, the year Japanese decide to build Kaohsiung Port, population growth trended to concentrate in Kaohsiung and Pingdong (Figure 9).

Figure 9. Population of cities and towns from 1903 to 1938. Kaohsiung and Pingdong as twin cores which were with rapid growth in Kao-Ping Delta after 1920 (Source: TDELS)



(O.4 - I.1, I2) regional division affected transportation

Following regional division, there were two important infrastructures need to be constructed. One was transportation which comprised roads and railroad. Railroad was mainly to link Kaohsiung and Pingdong as a major vessel; Roads connected small town to deliver agricultural products to local centers.

(O.4 - I.5) regional division affects hydraulic system

The other was hydraulic system, dam and dike system, which not only supplied dinking water to port area but also protected Pingdong Plain from flood. New dike system changed the direction of river from south-west to west, by which Pingdong Plain was encircled.

(O.4 - I.8) regional division affects irrigation

The original irrigation system, Tsoa-Kon-Zwin, had declined, because the regional function totally shifted from agricultural to port industrial. Agriculture in Kaohsiung was pushed toward east around Phonshan Hill, which stimulated the demand of new irrigation.

(I.1, I.2 - O.1) transportation and spatial pattern

Pingdong and Kaohsiung were built mainly following functional orientation which was based on grid system and infrastructure. In Pingdong, as a regional distribution center, the grid system developed along five main streets which met in front of station. In Kaohsiung, as an industrial port, there were three different direction of grid system in three phases of urban development.

(O.1 - O.2) spatial pattern and building type

Shop-house (Whan-tsou, 販厝), terraced house, following the development of grid system became a major building type in urban area. These shop-houses were usually two or three-floor houses with long and narrow layout.

(I.1 - I.9) road system affects draining system

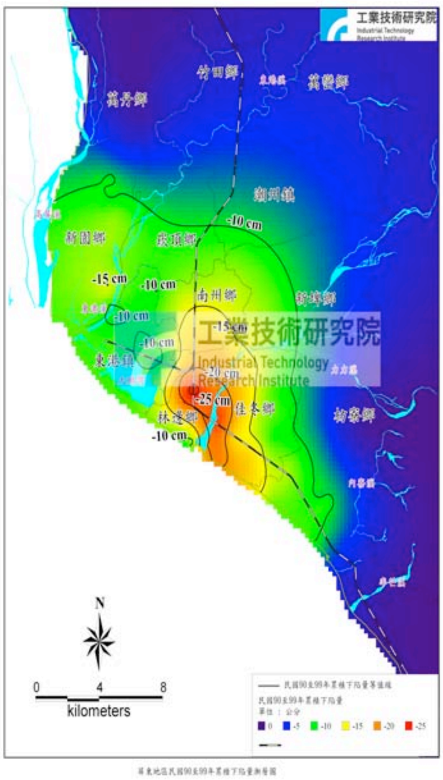
Public draining system was settled between road and arcade collecting household waste water to bigger channel and then draining to river.

Comprehensive analysis (Figure 12)

The main character of early Kaohsiung was built as a rear supply base to support the Japanese military need in south-east Asia. Sugar and other agricultural products were the important commodities for export. It means the delta had to spare large amount of land for agricultural function except port use. The construction of dike system which was supported by state not only protected Pingdong Plain from threat of flood but also provided the fresh water to Kaohsiung Port. New dike system forced original water ways to concentrate into one way, which created almost 6000ha reclaimed land. This land with main soils of gravel and sand was main groundwater recharge area. It means that the recharge of ground water rapidly decreased (Figure 10). In past, the down-stream region of Kao-Ping River was the area with abundant ground water. The residents in this area were used to dig wells for water. The living way of depending ground-water didn't change after the construction of new dike, which resulted in the unbalance between usage and recharge ground water. The rapid development of aquaculture along coast was the last straw to worsen land subsidence in 1970-1990. The subsiding rate was 10 – 15 cm per year (Figure 11). The sharp decreasing of ground water level also caused the invading of sea water into ground.

Figure 10. The pumped and recharged of ground-water in south Taiwan in 1936. (Source: Hydrologic Book of Taiwan)

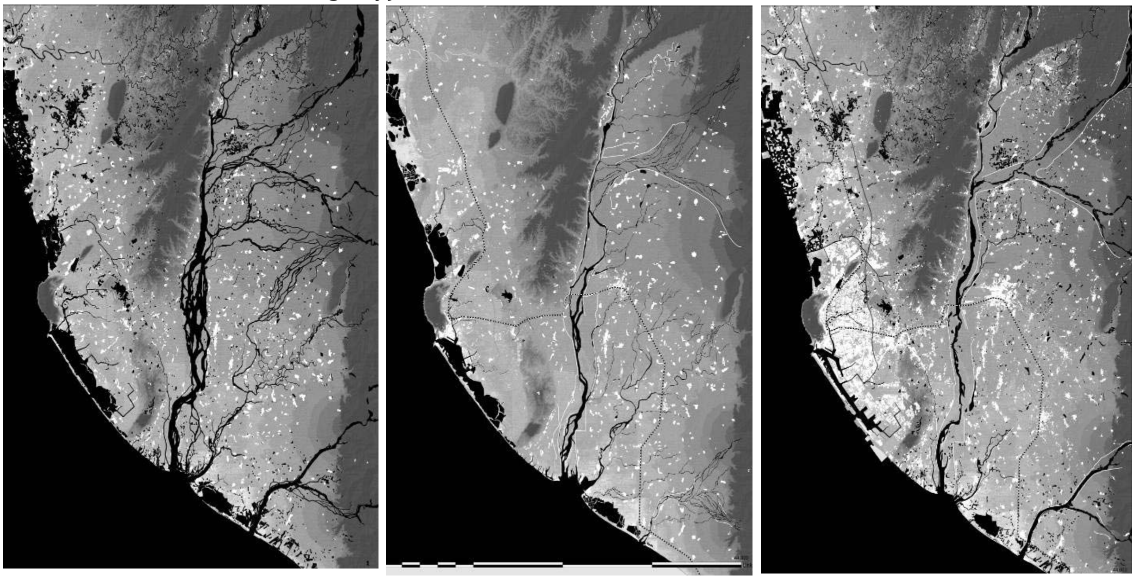
Figure 11. Land subsidence in Kao-Ping Delta (Source: Water Resources Agency http://www.subsidence.org.tw)



The dike also effected the sand contend of river. The sand, which originally shall be accumulated on flooding plain, following with the shifted river silted up in canalized river-bed. Most of the sand was blocked by Kao-Ping Dam, which not only heightened the river bed but also destroyed the instruments of water supplying especially after storm surges. The annual digging amount of silted sand in Kao-Ping River was around 5 millions square-meter. The fact which most of the sand could not be delivered into the sea by river resulted in the unbalance between erosion and supply of sand. The coastal erosion became a serious problem in Kaohsiung.

Transportation was an important element to develop urban patterns in Kao-Ping Delta. The grid system following road/ railroad system, rather than water system, dominated the spatial pattern, which affected the urban draining system, resulting in another type of flood. The diminishing of flood is very quickly. The flooding area usually located on the afflux point of huge run-off water. The waterfront along Love River in Kaohsiung and the south-west part of Pingdong became the jam of water flow which usually caused serious flood. Floods coming from overflow of river or extreme rainfall, coast erosion and land subsidence will be three tough tasks to confront the challenge of climate change in the future.

Figure 12. The comprehensive transformation of Kao-Ping Delta: white area is occupation; Black area is water system; White line is dike system; Black dot-line is railway and highway (Source: Academia Sinica; website of Water Resources Agency)



Conclusion

Following the analysis of layer based model, this research make some conclusions to explain the major issues in Kao-Ping Delta as following:

- About supplement of fresh water: Kao-Ping River provides 80% of drinking water of Kaohsiung city, but this supplying chain is quite sensitive. Due to heavy sediments the instrument of water cleaning was easily destroyed after storm surge. Ground water could be one of possible solution, but this issue must be concerned very carefully because of land subsidence. Based on three-layer approach, the rapid development of aquaculture was the last straw to cause the serious land subsidence along coast. The unbalance between supply and recharge of ground water, for quiet a long time in the past, is the major reason which needs to be further considered.

- About coastal erosion: The hydraulic system limits not only flowing water but also huge sediments, which keeps huge amount of sand within riverbed. Because much of the sand could not be delivered into the sea by water, the shortage of sand in coast worsens the condition of coastal erosion. It will be a serious problem when port confronts the threat of sea level rising in the future.

- About flood in highly urbanized areas: The development of urban fabric follows transportation rather than water texture. The afflux point of flowing water in grid system usually caused water jams. Once when the rainfall was too much to drain from these points it flooded. It will be an urgent problem when the extreme rainfall had become a quite common event in this region.

The inter-relationship of this three layer model provides several hints and a platform to collaborate with each other. Maybe it will take longer time to communicate; it is the best way to deal with the complex problem of climate change in delta in the future.

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