

*Full Research Paper*

## **Rapid Urbanization and Implications for Flood Risk Management in Hinterland of the Pearl River Delta, China: The Foshan Study**

**Hao Zhang \*, Wei-chun Ma and Xiang-rong Wang**

Department of Environmental Science and Engineering, Fudan University, Shanghai 200433, P.R. China; Tel. 86-21-55664052, Fax 86-21-65643343; E-mails: wcma@fudan.edu.cn; xrxrwang@vip.sina.com

\* Author to whom correspondence should be addressed. E-mail: zhokzhok@163.com

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**Abstract:** The purpose of this paper is to examine the linkage between rapid urbanization and flood risk in the hinterlands of the Pearl River Delta, P.R. China. Foshan, a typical hinterland city in the Pearl River Delta region, was selected as a case study. Land use and cover change in Foshan during 1988-2003 was analyzed using remote sensing and geographic information system (GIS) techniques. Furthermore, analysis on historical hydrological data during 1962-2005 was performed. Results show that rapid urbanization has resulted in losses of farmland, forest and shrub since 1988. In addition, in order to compensate or offset the loss of farmland due to rapid urban expansion, more than 30 % of the forest and 20 % of the shrub areas were transformed into farmlands. Inevitably, both the urban and agricultural lands increased the pressure on the drainage systems. Furthermore, over the past decades human activities such as dredging up the floodways, excavating sand and building water facilities in the rivers, significantly changed the hydrological conditions, and therefore impaired the rivers' capacity to buffer floods. Lessons from the Foshan case implied that, in addition to natural processes, human activities driven by socio-economic factors should be considered responsible for the recently increasing level of flood risks. Both economically and environmentally, it is irrational and impractical to encourage encroachment of lands vulnerable to floods. It is also realistic and urgent to effectively prevent and control the adverse ecological consequences of urbanization and economic activities for building their wealth and prominence.

**Keywords:** Urbanization; land use and cover change; remote sensing; GIS; flood; the Pearl River Delta

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## 1. Introduction

Land use and cover change (LUCC) and its impacts on the environment have been one of the increasing concentrations during on-going global changes [1-2]. Nowadays the percentage of urban area still only takes up a very small part of the Earth's surface [3]. However, expansion of human settlements and accompanying activities, especially the rapid urbanization occurring in the developing countries, play an important role in global land use and cover change [4], causing changes to ecological processes on a local and global scale. Among the impacts associated with LUCC, changes in hydrological conditions and flood risks have been the focusing issues. The causes of floods are closely related to topological, meteorological, climatic, biological and hydrological factors. Nevertheless, as witnessed by floods worldwide, land use and cover change associated with human activities may change the hydrological processes and increase flood risks [5-21].

As the largest developing country in the world, China has experienced prosperous economic growth and rapid urbanization over the last three decades. Since the late 1970s, the Pearl River Delta economic zone has been one of the major engines in propelling the rapid economic development of China. Benefited from its dominant locality, plentiful labor force, perfect urban infrastructures and competitive industrial chain systems, the Pearl River Delta economic zone, which consists of nine municipalities of Guangdong Province and covers 42600 km<sup>2</sup>, is now the economic center of Southern China. During the past three decades, the Pearl River Delta has experienced a rapid economic growth with associated expansion of urban areas. As a result, nearly 73 % of the population in this area now lives in urban areas [22-23].

Geomorphologically, the Pearl River Delta consists of three sub-deltas, namely the Xijiang River (West River), Beijiang River (North River) and Dongjiang River (East River) sub-deltas [24]. Benefiting from the fertile floodplains and advanced agricultural techniques, over the past thousand years the Pearl River Delta has been well known as a land flowing with milk and honey. However, the Pearl River Delta has historically also been a region vulnerable to flood damage. It was recorded that over the past century 45 severe floods occurred in this region, of which 36 severe floods occurred in 1900 and 1949. The 1915 flood, whose return period was 200 years, was the worst on record in many locations; it caused widespread damage throughout the Pearl River Delta. In was an extreme event, more than 935,000 ha of farmlands were damaged, some 6 million inhabitants were threatened, and 100 thousand inhabitants died or were injured [25-27].

In this region, when the cities in the threat of floods become one of the centered problems, much attention was paid on the hydrological factors of the river system on relatively fine scale [25-26, 28-33]. However, on the meso- or larger scale, the linkage between flood damage and anthropogenic impacts should be taken into consideration. This will be helpful to make an integrated approach for flood management.

The subject of this study was the city of Foshan. Over the past three decades propelled by the prosperous labor-intensive industries, Foshan has been one of the most attractive economic sub-centers of the Pearl River Delta. Due to its location and economy, Foshan lends itself well to an analysis of examining the relation between dramatic land use and cover change and increasing flood risk. Floods in Foshan had traditionally been a result of lower lands which were subject to flood risk. Nine catastrophic floods occurred during 1949-2005, of which three floods recently occurred in 1994-2005 caused severe damage to this region [26-27]. Obviously, frequency of floods and subsequent flood risk has been much higher than ever.

The aim of this study is to analyze the dynamics of land use and cover changes for Foshan City, especially focusing on recent increase in flood risk as a result of joint effects of natural processes and human activities. Nevertheless, it is expected to provide rationale suggestions for management of flood risk at local and regional level.

## 2. Study area

Foshan is located between latitudes 22° 38' N and 23° 34' N, and longitudes 112 ° 22' E and 113 ° 23' E. This area has a subtropical climate with an annual temperature of around 20–25°C. Annual precipitation inside the study area varies widely from 1,600 to 2,000 mm, of which about 80% is received during April and September, namely during the flood season. Geomorphologically, this area dominantly consists of plains and hills, of which the percentages are 70.9 % and 20.0 % respectively. The hills are mainly located at the north and southwest parts, and the highest elevation is 805 m. The plains consist of the 'high sub-delta plain' and the 'sub-delta plain'. The 'high sub-delta plain' is mainly in the east, north and northwestern parts, of which the elevation is 5-12 m. The 'sub-delta plain' is mainly in the southeastern part, of which the elevation is 2-3 m. In this area the Xijiang River and Beijiang River are two major rivers encompassing the 'high sub-delta plain' and the 'sub-delta plain'. The Xijiang River has 11 branches, and Beijiang River has 13 branches. The total length of the two mainstreams and the branches is 501.4 km, and the watershed area is 1,685 km<sup>2</sup> [26-27].

The city of Foshan is the third most populous city in the Pearl River Delta region, and it is now an emerging metropolitan covering an area of 3,813 km<sup>2</sup>. Administratively, Foshan consists of five districts: Chancheng, Shunde, Nanhai, Sanshui, and Gaoming (Figure1). In the end of 2005 the GDP per capita was 41,031 RMB Yuan (equivalent to \$5,007), and the number of permanent residents in Foshan was 5.80 million [23].

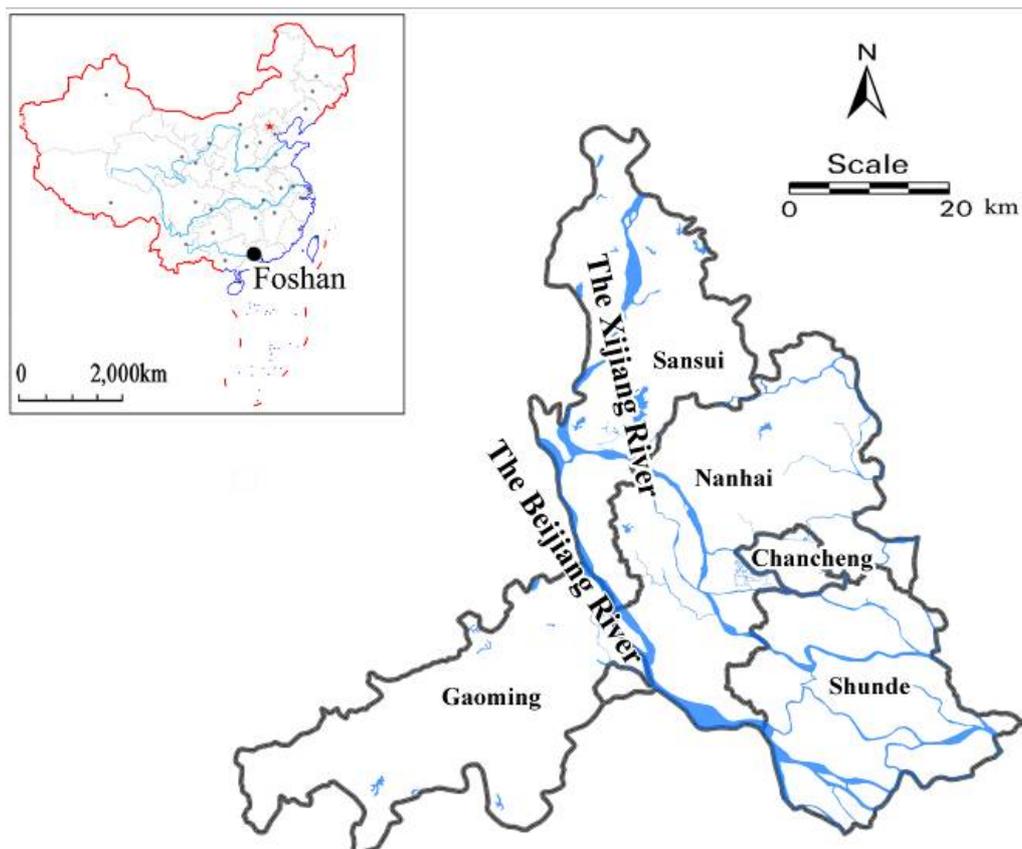
## 3. Methodology

### 3.1 Maps processing

Two remotely sensed images were selected for this study. One is a Landsat Thematic Mapper data (TM-5) dated December 17, 1988 and another is a Landsat Enhanced Thematic Mapper plus data (ETM+) dated December 28, 2003. Both of the images were clear and nearly free of clouds. Accordingly, the study period covered about 15 years. Due to lack of available land use maps prior to the 1990s, alternatively a GIS-based topographical map (1:50,000 scale) acquired in 1996 and a land use map (1:100,000 scale) acquired in 2003 were used as reference data and for accuracy assessment.

Prior to interpretation, the images were geometrically rectified according to the Krasovsky 1940 spheroid and a common UTM coordinate system (Beijing 1954 system). The images were resampled to 30 meters using the nearest Neighbor algorithm to keep the unchanged original brightness values of pixels, and the RMSE were both found within 1 pixel. The image processing and data manipulation were conducted using algorithms supplied with the GEOSTAR® image processing software. Furthermore, ESRI ARCGIS® was used for spatial analyses.

**Figure 1.** Location of the study area.



Land use and land cover patterns for 1988 and 2003 were mapped by the use of Landsat TM data and Landsat ETM+ respectively. According to a predetermined classification scheme of seven categories of land covers present within the study area and their image characteristics, bands 5, 4, and 3 for Landsat TM/ ETM+ images were combined to produce visually images. These covers include urban or built-up land, farmland, forest, shrub, water (mainly rivers, streams and reservoirs), bare land, and dike-pond land. Herein, the classification scheme of the study area was modified on the basis of the land use classification system by China National Committee of Agricultural Divisions [34].

### 3.2 Accuracy Assessment

Two maps of seven covers were produced from the respective satellite images. Based on the reference data of digitalized land use map, for each image 100 training sites were chosen to ensure that

all spectral classes covering each land use and land cover category were adequately represented in the training statistics. The overall accuracy of the land use/cover maps for 1988 and 2003 was determined to be 87.63 % and 86.98 %, respectively (Tables 1 and 2). Furthermore, the supervised signature extraction with the maxi-mum likelihood algorithm was employed to perform the classification of the satellite images. Also, for each image 250 samples were randomly selected to check the accuracy of the classified maps, and the KAPPA indices for the 1988 and 2003 maps were 86.1 % and 91.3 % respectively, which meet the recommended value by Lucas *et al* [35]. Clearly, these data was available for further study.

**Table 1.** Land cover classification accuracy assessment for 1988.

Classified	Reference							Sum	UA (%)
	Built-up	Water	Forest	Dike-pond	Farmland	Shrub	Bare land		
Built up	12	0	0	0	0	1	2	15	80.0
Water	0	15	0	1	0	0	0	16	93.75
Dike-pond	0	2	0	11	0	0	0	13	84.62
Forest	0	0	18	0	1	1	0	20	90.00
Farmland	0	0	2	0	15	0	0	17	88.24
Bare land	0	0	0	0	0	0	12	12	100.0
Shrub	1	0	1	0	0	14	0	16	87.50
Sum	13	17	21	12	16	16	14		
PA (%)	90.4	89.47	84.65	93.43	91.97	89.66	85.71		
OA (%)								87.63	

Note: PA means Producer's accuracy; UA means User's accuracy; OA means overall accuracy.

**Table 2.** Land cover classification accuracy assessment for 2003.

Classified	Reference							Sum	UA (%)
	Built-up	Water	Forest	Dike-pond	Farmland	Shrub	Bare land		
Built-up	14	0	0	0	0	0	1	15	93.33
Water	0	15	0	1	0	0	0	17	88.24
Dike-pond	0	0	16	0	1	1	0	19	84.21
Forest	0	1	0	10	0	0	0	12	83.33
Farmland	0	0	1	0	14	0	0	16	87.50
Bare land	0	0	3	0	0	9	0	12	75.0
Shrub	1	0	0	0	0	0	15	16	93.75
Sum	15	17	21	12	16	10	16		
PA (%)	93.11	90.66	76.83	85.29	85.39	90.0	93.75		
OA (%)								86.98	

Note: PA means Producer's accuracy; UA means User's accuracy; OA means overall accuracy.

### 3.3 Land use and land cover change detection

A cross-tabulation detection method was employed to perform land use and cover change detection. The land use change matrix was produced, which showed quantitative data of the overall land use and cover changes between 1988 and 2003 in the study area. Based on the main types of gains and losses in each category shown by the change matrix, land use transfer images and land use transfer matrix for each category were also produced.

## 4. Results and discussion

### 4.1 Land use dynamics

Figure 2 shows that land use conversion among different land use types occurred during 1988-2003. As shown in Table 3 and Figure 3, the areas of dike-pond, farmland, and built-up land increased 25,030 ha, 7,020 ha and 41,280 ha, respectively. The annual change rate of dike-pond, farmland, and built-up land were 1,668.7 ha yr<sup>-1</sup>, 468 ha yr<sup>-1</sup> and 2,752.0 ha yr<sup>-1</sup>, respectively. In contrast, areas of water, fallow land, shrub, and forest decreased 2,990.0 ha, 2,400.0 ha, 22,480.0 ha, and 45,460.0 ha, respectively. Correspondingly, annual change rate of water, bare land, shrub, and forest decreased 199.3 ha yr<sup>-1</sup>, 160.0 ha yr<sup>-1</sup>, 1,498.7 ha yr<sup>-1</sup>, and 3,030.7 ha yr<sup>-1</sup>, respectively.

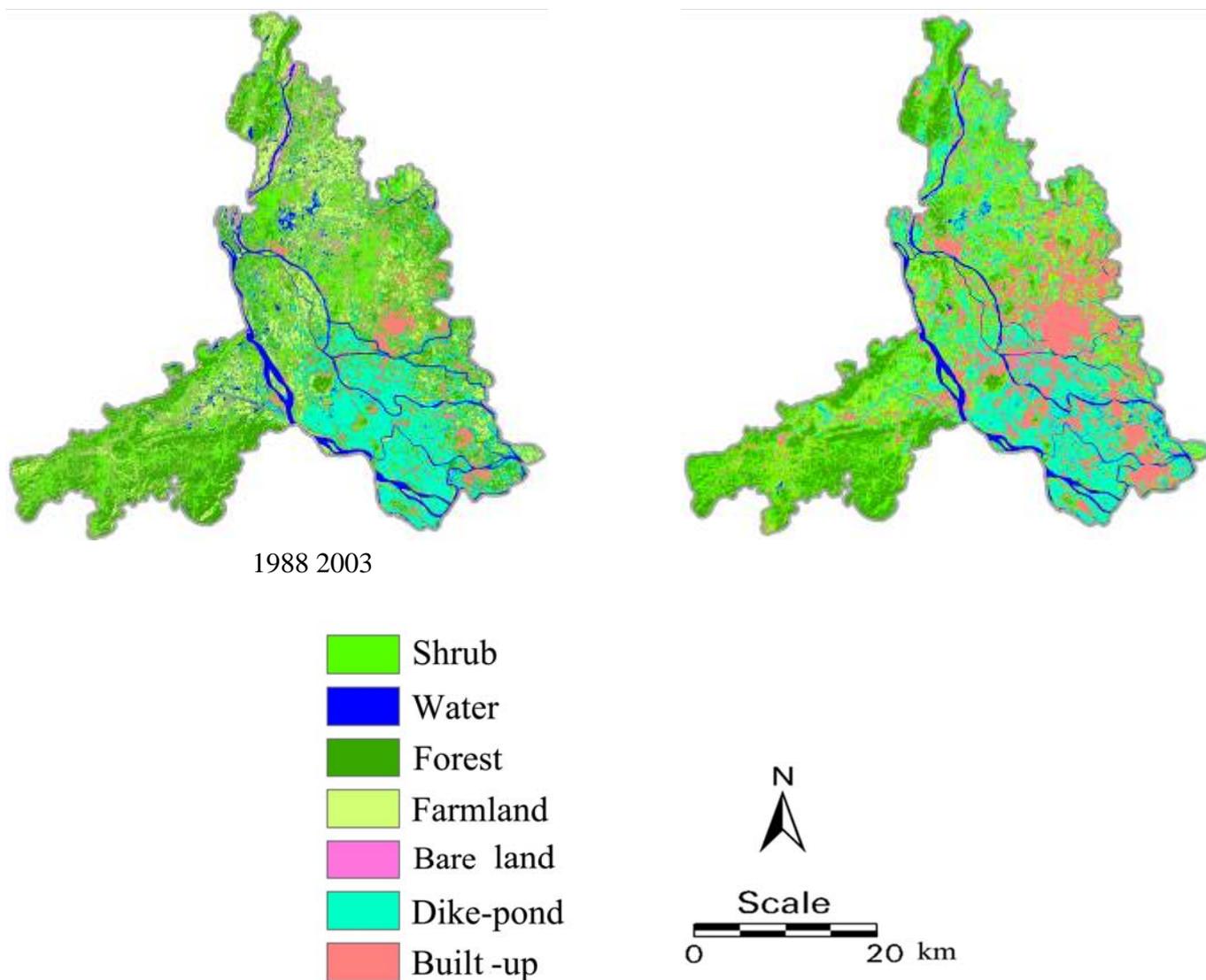
**Table 3.** Land use transfer matrix in Foshan during 1988 and 2003.

<i>Land use type</i>	<i>Water</i>	<i>Dike-pond</i>	<i>Farmland</i>	<i>Bare land</i>	<i>Forest</i>	<i>Shrub</i>	<i>Built-up</i>
Water	42.12	5.48	1.60	3.57	1.23	1.48	2.31
Dike-pond	26.72	55.52	25.19	17.11	17.26	12.03	11.42
Farmland	13.29	14.62	29.68	28.59	21.64	23.37	14.16
Bare land	3.72	2.94	3.73	5.91	2.45	3.85	2.03
Forest	4.63	4.30	15.05	14.85	30.38	21.36	5.98
Shrub	2.92	1.82	11.20	16.43	13.75	16.02	4.13
Built-up	6.64	15.33	13.55	13.54	13.29	21.88	59.94

Note: The columns and rows contain data of 1988 and 2003 respectively.

Approximately 60 % of the newly built-up area was mainly converted from 34.4 % of dike-pond, 19.3 % of farmland, 19.1 % of forest and 26.0 % of shrub, respectively. Simultaneously, 26.1 % of the newly dike-pond was mainly converted from 35.8 % of farmland, 24.8 % of forest and 14.3 % of shrub, respectively. Nearly 8.6 % of newly farmland was mainly converted from 32.9 % of dike-pond, 31.1 % of forest and 27.8 % of shrub, respectively.

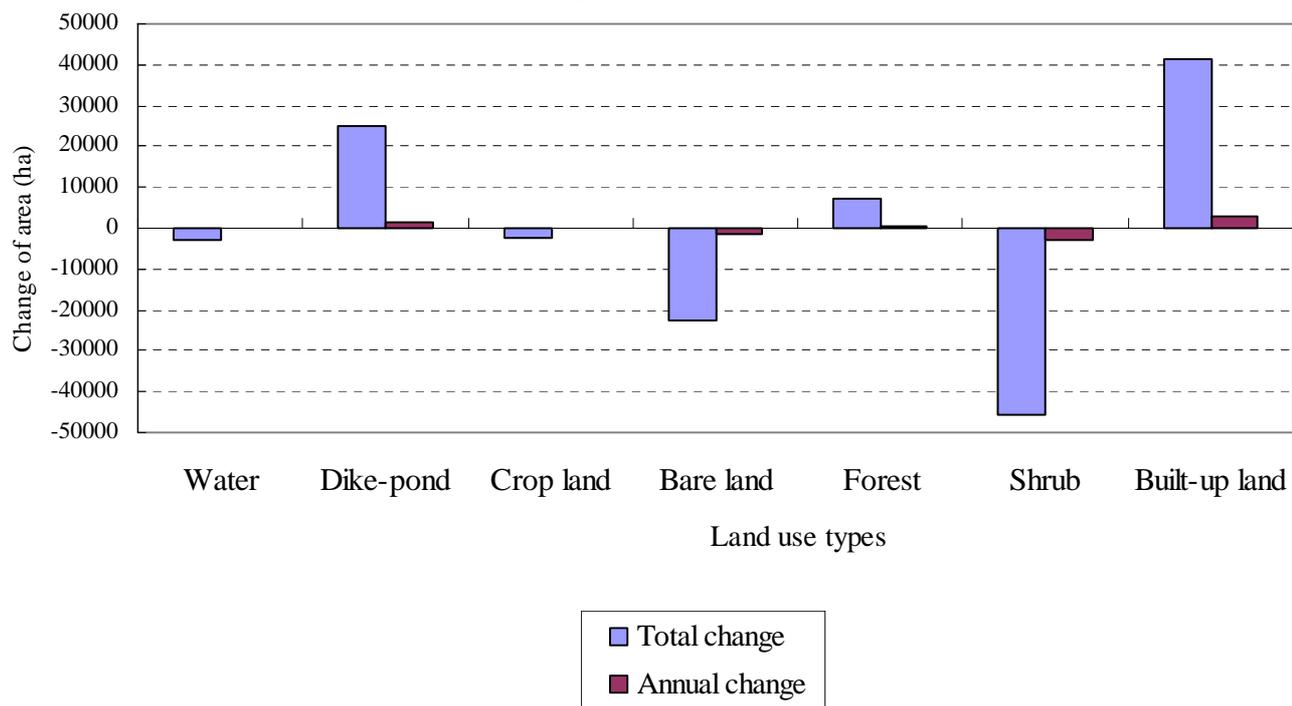
**Figure 2.** Land use changes in Foshan during 1988-2003 (the left and right maps show land use in 1988 and 2003, respectively)



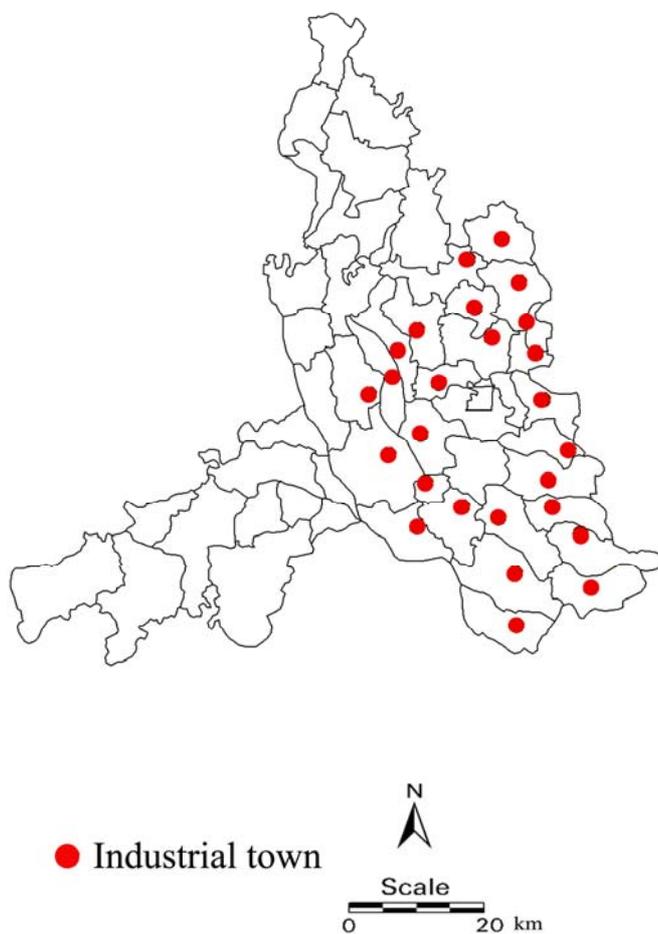
#### 4.2 Urban developmental pattern

Table 4 shows the temporal and spatial expansion of urban or built-up areas in 1988-2003. Traditionally, the extent of urban or built-up land was well developed within the city core of Foshan, namely Chancheng district and Guicheng, the urbanized area of Naihaidistrict. However, with the emerging inter-city highways leading to Guangzhou, Zhongshan, Dongguan, Zhuhai, Shengzhen, Hongkong SAR and Macao SAR, closer economic relations between Foshan and city groups in the Pan-Pearl River Delta were established. Thus, the major industrial towns along the highways across Chancheng, Naihaidistrict, and Shunde developed rapidly (Figure 4). Currently, these industrial towns are well developed manufacturing bases, which are famous for industrial and domestic pottery, building materials, chemical mechanism, electronic equipments, textile, and information industries in China.

**Table 4.** Total and annual changes of land use in Foshan during 1988 and 2003.



**Figure 4.** Pattern of the industrial towns in Foshan.



During the rapid economic growth more than 1 million workers from the other cities and local farmers who lost their lands were employed by the industries. As a result, significant socio-economic transformation occurred at the above towns, where the dominantly productive agricultural lands gave their way to urban areas. However, under the growing pressure of land request for accelerated industrialization and urbanization, the usage of both productive and non-productive lands was changed, and therefore the industrial park and urban areas increased significantly. In contrast, due to limited topographical features and weak economic relation between neighboring cities around Foshan, only a few towns of Sanshui and Gaoming along the inter-city highways developed. In summary, economically, urban pattern of Foshan was characterized with rapid industrialization and subsequent socio-economic transition. Spatially, based on comparison of land use/cover change maps at two stages, the urban growth shows the pattern of city-core centered sprawling along the highways. Moreover, since most of the intensive industrial parks and major towns are located in the plains where the inter-city highways run across, it can be predicted that two city cores of Chancheng-Guicheng (which links Foshan and Guangzhou and extends to Dongguan, Shenzhen, and Hongkong SAR) and Shunde (which links Foshan and Zhongshan and extends to Zhuhai and Macao SAR) will come into being, and land use change will be accelerated at high rate in the near future.

#### *4.3 Flood hazards as a response to urbanization and land use*

On the local and regional scales, flood risk as a response to urbanization and LUCC can be interpreted with following aspects:

##### *4.3.1 Flood hazards associated with urban sprawl and declining drainage system*

Our results show that nearly 15% of the water bodies (not including dike-pond land) decreased over the study period. Spatially, annual change rates of water bodies in Changchen, Nanhai, Shunde, Gaoming, and Sanshui were -72.77 %, -7.45 %, -18.09 %, -4.47 %, and -3.7 %, respectively. Not surprisingly, as mentioned in section 4.2, rapid urban sprawl occurred in the traditional city core in Changchen (including urban area of Nanhai) and another newly city core in Shunde, where the loss rates of water bodies were much higher than that in the other districts. This may be attributed to rapid urban sprawl and associated land use changes. Due to very scarce land resources for urban development, many minor streams and ponds were filled for building. Therefore, within inner urban area many small water bodies vanished and were replaced with regularly modified ditches. Recently some dams have been built to control aquatic environment of the conserved water bodies, but this significantly increased the sediment and therefore caused decline in urban drainage system. The present urban drainage system ran well in the case of the 24-hour lasting rainfall, of which return period was 10 years. However, as a response of removal of vegetation in and around the urbanized and urbanizing areas, increase in runoff volume was directly related to sprawling impervious surfaces. In comparison to well vegetated land covers which influence the infiltration and saturated hydraulic conductivity via roots and pores resulting from soil fauna [36], impervious surfaces were regarded as an extreme example in increasing overland flow velocity and floodplain flow rates. This increased the pressure of the drainage canals and caused the rising water level of inner rivers, dikes and major rivers during the heavy rainfall. In summary, all these may result in the increasing runoff and abnormal water

level rise during the rainfall season, which, in turn, caused overload of the limited drainage systems and increased the risk of floods.

#### 4.3.2 Flood hazards associated with irrational land use along the rivers

Historically, within Foshan's territory most of built-up land and fertile farmland were located in the lower floodplains, where the elevation ranges between 0.4-2.0 m. It was estimated that the total area of lands, which were subject to flood risk, added up to 1,245.8 km<sup>2</sup>. The strong demand for protecting the farmlands and populous settlements has accelerated construction of the water facilities and flood control systems. Since 1990, the Foshan municipal government spent 0.5% of GDP on infrastructure projects annually, and that amount will increase to 1-2% or higher in the future [26]. However, in order to meet the demand of urban development, intensive human activities, including excavating sand, building bridges, dams, and docks, dredging up the waterways for shipping, were encouraged. Also, the uncontrolled development of factories and farmlands were permitted along the rivers. Until recently 11,793 households and 60,081 residents had settled in the flooding zone [27]. These significantly changed hydrological conditions of the rivers. Herein, the diversion ratios of flow measured at Sanshui and Makou sites were employed to indicate the changing flow flux of the Beijiang River versus Xijiang River respectively. As shown in Figure 5, during the 1960s-1980s annually averaged diversion ratio of flow at Sanshui site (indicating flow flux of the Beijiang river) ranged between 13-14%, which was much lower than that at Makou site (indicating flow flux of the Xijiang river). However, a sharp increase in annually averaged diversion ratio of flow was observed since the 1990s. Present averaged diversion ratio of flow increased to about 25%, this represents a sharp increase in flow flux of the Beijiang River. Together with the reinforced levees, docks and other water facilities along the mainstreams, which inevitably decreased the cross section of the rivers, the increasing overload of flux across the Beijiang River and its downstream would aggravate the flood risk in the case of extreme events.

**Figure 5.** Annually averaged diversion ratio of flow flux at Sanshui and Makou sites.

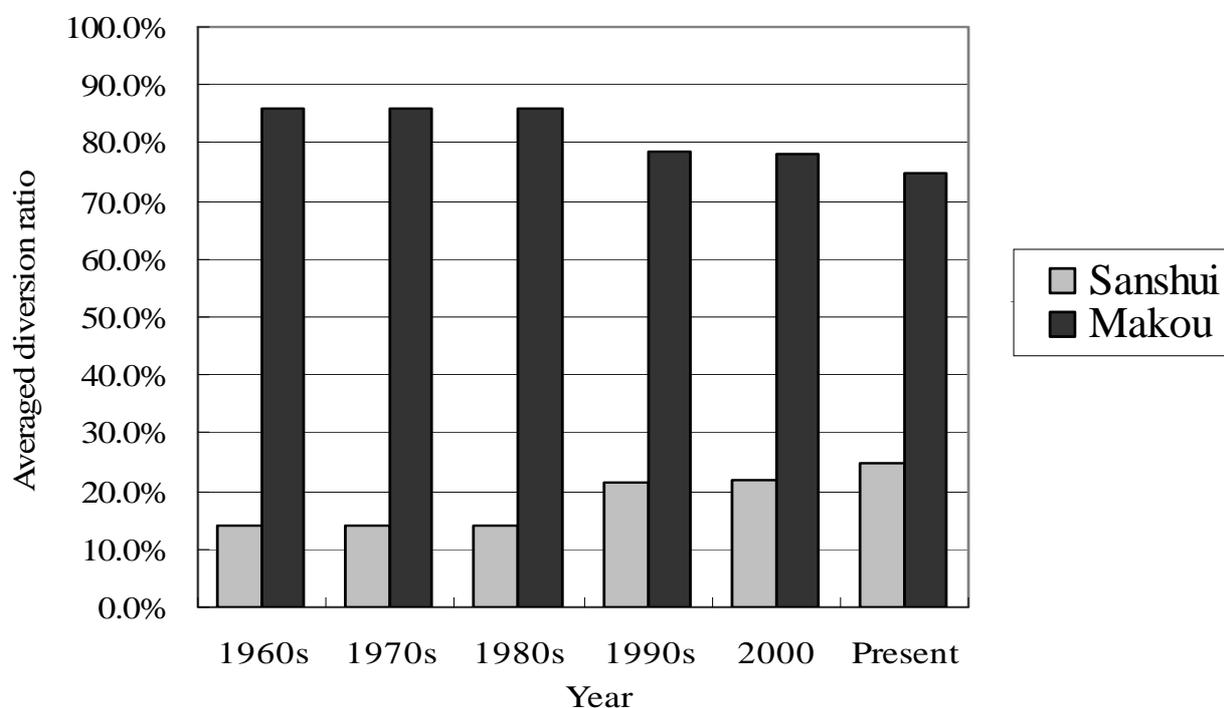


Table 5 shows significant changes in flood risks during three recent catastrophic events. However, two sets of referencing water level systems (the 1982 and 2002 systems) for flooding control and prevention were still in use, and sometimes they showed puzzling results. Herein, based on a hydrological survey of river systems carried out in 1998-1999, the 2002 system worked better than the 1982 system [28], the newly referencing water level system was used instead. Spatially, most of the urbanizing and urbanized lands sprawled along the middle and downstream sections of the Xijiang River and Beijiang River.

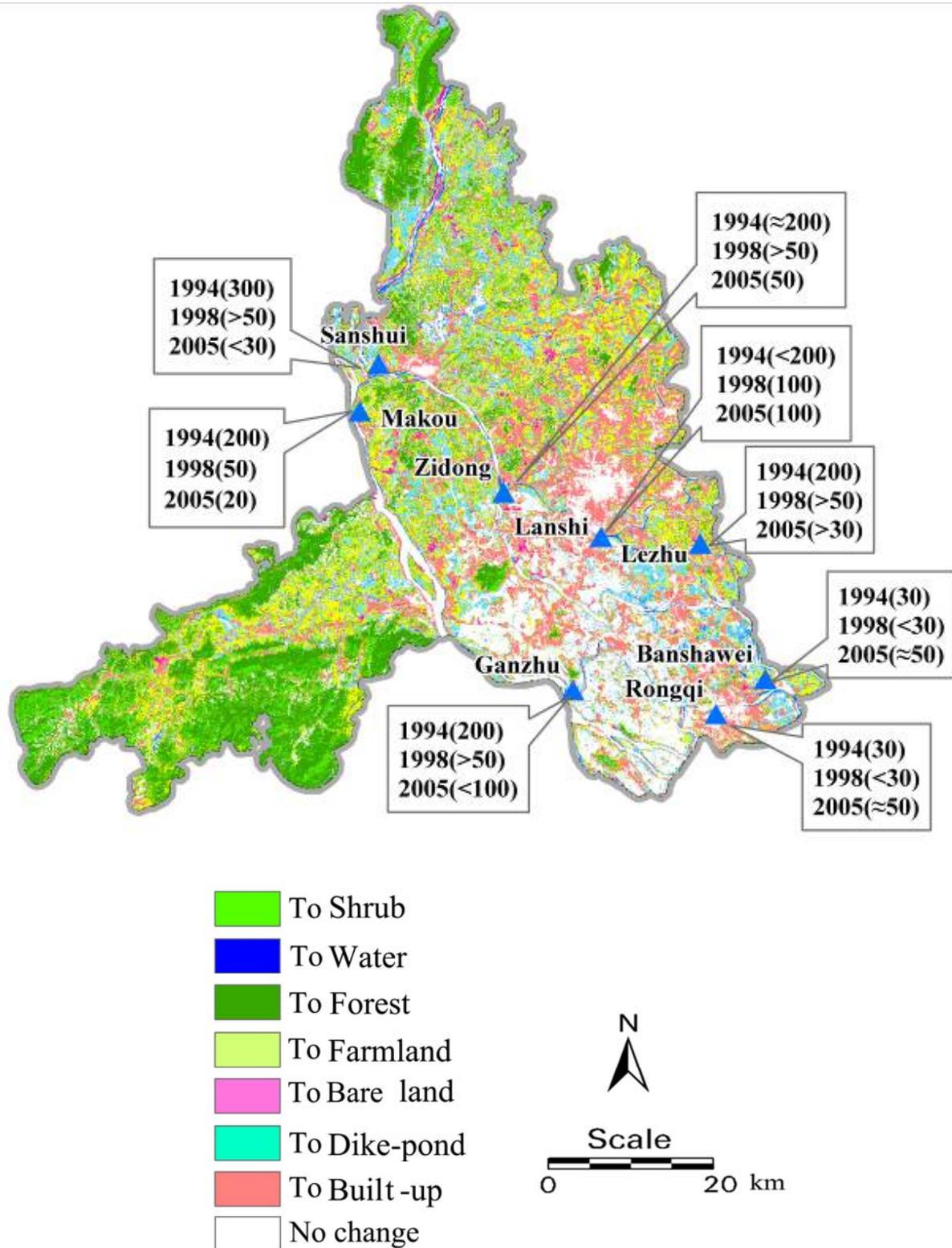
**Table 5.** The highest water level and maximum flow flux of three recent flood peaks recorded at the hydrological sites [31].

<i>Hydrological sites</i>	<i>the highest water level (m)</i>			<i>the maximum flow flux (m<sup>3</sup>/s)</i>		
	1994	1998	2005	1994	1998	2005
Makou	10.01	9.42	8.92	47000	46200	53200
Sanshui	10.38	9.59	9.19	16200	16200	16400
Zidong	7.62	7.3	7.2	N	N	N
Lanshi	6.01	5.84	5.81	N	N	N
Lezhu	3.57	3.77	3.8	N	N	N
Ganzhu	6.79	6.32	6.44	N	N	N
Rongqi	3.96	3.92	3.99	N	N	N
Banshawei	3.16	3.16	3.14	N	N	N

Note: N means data not available.

Figure 6 shows the coupled relationship between land use change and flood risks along the mainstems in Foshan. As indicated by the highest water levels recorded at Makou and Sanshui sites, the upstream sections witnessed the worst 1994 flood. For the Beijiang River, the return period of the flood was 200 years. For the Xijiang River, return period of the flood was 300 years. Simultaneously, except for two downstream sites in Shunde district, most of the middle reaches and downstream sites witnessed the severe flooding, whose return period was about 200 years. Compared with the 1994 event, the upstream sections witnessed the less severe floods during the 1998 and 2005 events. Thus, flood risk seemingly decreased at the upstream sections. This may be attributed to the activities of excavating sand and dredging up the upstream floodways, which lead to the broader cross section and the decreased riverbeds at the upstream sections [29-31]. However, the sharp decrease in water levels also caused severe soil erosion during drought at the upstream sections; this partly caused the elevated riverbed at the middle and downstream sections of the Beijiang River. As a result, during the 2005 floods the increasing maximum flow fluxes at Sanshui and Makou revealed large volume of streams passed through the upstream cross sections, whereas at the middle reaches and downstream sites of Lanshi, Ganzu, Rongqi, Lezhu, and Banshawei, the elevated riverbeds and narrower cross sections impeded the flood peaks. This can help explain that the highest water levels reached to that of the past floods, with return periods of 50-100 years in 1998 and 30-100 years in 2005, respectively.

**Figure 6.** Spatial relationship between land use change in 1988-2003 and occurrence of the extreme floods with different return periods (in brackets) in 1994,1998 and 2005.



On large scale natural factors such as extreme rainfall storm, overflow of river banks, and change in hydrological conditions of the rivers should be dominantly responsible for abnormal floods. On local scale, rapid urban sprawl has caused an increase in the magnitude of impervious land and subsequent runoff. Nevertheless, over the past decades the reinforced dams and levees have recently worked

poorly in flood control and prevention due to the aging water facilities. It was noted that approximately 80 % of the water facilities must be reinforced to defend from floods. Besides, most of the present levees around the newly urbanizing and urbanized area can only defend from floods with return periods of 20-50 years [26-27]. Moreover, in the case of previous adverse floods, discharged flow flux from the upstream Feilicia dam increased the magnitude and frequency of peak flows in the Beijiang River [37]. Therefore, given the compound effects of natural and anthropogenic factors, the middle reaches and downstream areas of the 'sub-delta plain', especially the rapidly urbanized area of Changchen-Nanhai and Shunde will be more subject to the disastrous floods in the case of extreme events.

#### *4.4 Implications for sustainable management of flood risk*

For political and economic reasons, reducing the vulnerability of urban and rural towns to floods and associated hazards has been a very pronounced priority by local and provincial governments. Thus, much attention should be paid to both technical and institutional innovations.

Technically, successful management of flood risk depends on a complete understanding of hazard identification and risk assessment. Lessons from previous extreme events noted that floods and associated hazards must be managed in an integrated floodplain basis rather than as random emergencies on local and fine scales. Therefore, an integrated approach is urgently needed. Unfortunately, there was not an integrated early warning system for flood risk management in this region yet. It is urgent to produce the flood-risk maps, which will provide valuable information to local and senior governments for flood relief. Currently, with wide application of GIS and remote sensing techniques, the goal will be achieved by using key parameters of historical and real-time levels, including precipitation pattern, water levels, tidal levels, flow fluxes, land use patterns, population density, and flooded area. Thus, information on warning levels can be rapidly communicated to the municipalities and communities for preparedness levels and remedial measures.

Institutionally, the implementation of policies for flood prevention and relief plays a key role in effective flood management. Like the other places in China and elsewhere, a top-down approach has dominated regional flood fighting efforts. As the formidable flood fighting efforts led by the local governments, more than ten thousand military personnel and volunteers were called up to fight the floods in cases of emergency. Usually, responses to past flood damage prompted increasing construction of water facilities. This required more investment in flood risk prevention. In addition, the emphasis on construction of water facilities has fostered an inappropriate idea of land use based on a false sense of security. In pursuing short-term economic gains, local governments failed to effectively managed land development in the flood-prone areas. In Foshan, due to human activities such as building dams and bridges, excavating sand, expanding farmlands along the riverside, the ongoing encroachment of flood-prone areas resulted in increasing vulnerability of the existing water facilities. These are very common in the Pearl River Delta region. If these developments are flooded and caused more severe risk losses, local governments would inevitably be blamed for their capacity in dealing with the emergency. However, it should be noted that those developers, who occupied flood-prone area, must be more responsible for their actions and less dependent on current relief policies and rehabilitation initiatives by the governments and insurance companies. Therefore, on local and

regional scales, legislative actions must be taken to strictly control the intensive development in flood-prone areas. Moreover, local and senior governments should make practicable policies on land use planning to help change the current cultures of dependency.

## 5. Conclusions

Remotely sensed imagery and historical hydrological data were employed to examine the linkage between land use and cover change and flood risk in Foshan. Results show that rapid urbanization in Foshan has resulted in loss of farmlands, forests and shrubs since 1988. Approximately 60 % of the newly built-up land was mainly converted from 34.4 % of dike-pond land, 19.3 % of farmland, 19.1 % of forest and 26.0 % of shrub, respectively. In addition, in order to compensate or offset the loss of farmland due to rapid urban expansion, more than 30 % forest and 20 % shrub were changed to farmlands. Inevitably, both the urban and agricultural lands increased the pressure of the drainage systems.

Furthermore, analysis on historical hydrological data during 1962-2005 showed that over the past decades human activities such as dredging up the floodways, excavating sand and building water facilities in the rivers, significantly changed the hydrological condition, and therefore impaired the rivers' capacity of buffering the floods. Similarly, on local and regional scales, the ongoing urbanization and associated land use change have impaired the function of draining systems and increased flood risk in the Pearl River Delta region. Lessons from the Foshan case implied that, in addition to natural processes, human activities driven by socio-economic factors may be responsible for the recently increasing level of flood risks. Therefore, both economically and environmentally, it is irrational and impractical to encourage encroachment of lands vulnerable to floods. It is also realistic and urgent to effectively prevent and control the adverse ecological consequences of urbanization and economic activities for building their wealth and prominence.

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