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# An integrated analysis of urbanization-triggered cropland loss trajectory and implications for sustainable land management

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ABSTRACT

This paper demonstrates an integrated method for studying cropland loss dynamics and the resultant impacts on sustainable development spanning the past 10 years (1996–2006) in response to rampant urban growth. This study deploys remote sensing to obtain accurate measures of cropland change information and applies GIS to examine the spatio-temporal trajectory of cropland loss. Coupled with landscape metrics and soil quality assessment approach, this paper also explores the impacts on fragmentation of cropland landscape and soil resource in detail. The case study concludes that cropland has undergone considerable loss from 1996 to 2006 and exhibited distinct variation of change dynamics between 1996–2000, 2000–2003 and 2003–2006. In the meantime, cropland loss was spatially concentrated in Jianggan, Xihu and Binjiang districts. However, these changes have caused an increasingly fragmented composition and dispersed distribution of cropland landscape over the time. Moreover, the study further documented a severe competition between urban development and good quality soil concomitant with the rapid urbanization process. In addition, some distinct soil types, with their unique physical structure and history of formation, may be in the verge of disappearance. The permanent loss of valuable cropland and increasing fragmented landscape patterns along with continued urban sprawl may also impose potential threat on the sustainable development and food security of the region.



## Introduction

China is a nation with the largest population but the lowest cropland acreage per capita which is less than half of the world's average (Ji et al., 2001; Tan, Li, Xie, & Lu, 2005; Yang & Li, 2000). Since the mid-1980s, the encroachment of cropland for urban growth has been arguably the most widespread and intensive in Chinese history, and in no region has the process been more frenzied than in the eastern plain and river basins, especially in the Yangtze River Delta and Pearl River Delta, characterized not only by their sheer scale but also by unparalleled rapidity of changes (Chen, 2007; Ho & Lin, 2004; Xie, Yu, Tian, & Xing, 2005). More alarmingly, fertile and productive arable land entailed with rich water and climate resources are located in these regions where valuable cropland has been challenged from the rampant urban growth. In spite of these challenges, the rapid urbanization process could not be halted in the short term because of the existing 455.94 million urban population has not claimed its dominance in the nation. Chinese authorities anticipated that China would have half of its population living in cities and towns by 2015 implying an increase of at least another 250 million urban people in the coming future. Inevitably, the tremendous decline in cropland acreage could potentially impose a substantial threat to the sustainable development of China and raise concerns at the highest levels of government about the food security for its 1.3 billion people. Given China's enormous population size and its growing interaction with the world's economy, there are good reasons to assume that the processes of accelerated urbanization and notable cropland loss unfolding in China will have far-reaching economic, social, political and environmental implications, not only for the largest developing nation, but also for the globalizing world.

Central to much of the debate is the difficulty in acquiring accurate measurements of the area of urban land use, monitoring changes in urban land use and assessing the impact of these changes on agricultural land area in a way that can be used in rational and cost-benefit analysis (Zhang, Chen, Tan, & Sun, 2007). Comprehensive information on the trajectory of cropland

*Abbreviations:* PCA, principle component analysis; SQI, soil quality index.

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loss and systematic evidence on the causes, distributions, rates and consequences of those changes are urgently needed by the central and local government to formulate new and more effective legislation and policies for arable land protection and conservation. Coupled with the ready availability of historical remote sensing data, reduction in cost and increased resolution, remote sensing technology appears poised to make an even greater impact on planning agencies and land management initiatives (Rogan & Chen, 2004). Consequently, issues related to agricultural land change using remote sensing techniques have attracted interest among a wide variety of researchers (Chen, Chen, Shi, & Tamura, 2003; Islam & Weil, 2000; Shavol, 2008; Tian et al., 2005; Yeh & Li, 1997, 1999; Zhang et al., 2007). However, most of these studies have centralized on the land use change dynamics and its driving forces. Few studies have put insights into the profound consequences of cropland loss comprehensively which is a critical issue for sustainable development and bears paramount political and security implications. In addition, despite the emergence of coastal economic-developed regions like Hangzhou, research on urbanization in China is still heavily skewed towards a few cities at the top of the urban hierarchy, such as Shanghai, Beijing and Guangzhou (Wei & Li, 2002).

To fill this gap, Hangzhou which is one of the most rapidly developing costal regions in China has been selected for a case study. This study primarily aims to examine the spatio-temporal cropland loss and its consequence on sustainable development in response to rampant urban growth. The paper also develops an integrated method combing remote sensing technique, GIS, landscape metrics and soil quality assessment approach to address these research questions.

## Materials and methods

### *Study area*

Hangzhou is the capital of Zhejiang province and located in the southern of the Yangtze Delta which is China's emerging global city-region (Fig. 1). Situated in one of the China's richest regions, Hangzhou has long been one of the country's most important cities. Established during the Qin Dynasty (222 BC), it is among the traditional capitals of China, and was praised by Marco Polo as one of the greatest cities in the world.

Over the years, the city's total population grew from 1.05 million in 1978, the year when the China initiated economic reform, to 1.67 million in 1996 and then to 1.79 million in 2000, making it one of the largest cities in the country. After the incorporation of the cities of Xiaoshan and Yuhang in 2001, Hangzhou's total population reached 4.14 million in 2006, ranking it sixth among Chinese cities. More surprisingly, its gross domestic production (GDP) had significantly increased from 47.27 billion RMB in 1996 to 273.78 billion in 2006, which is among the top five most economically competitive cities in mainland China. This magnitude of growth and transformation in such a short period is likely unparalleled among cities in transition economies and developing

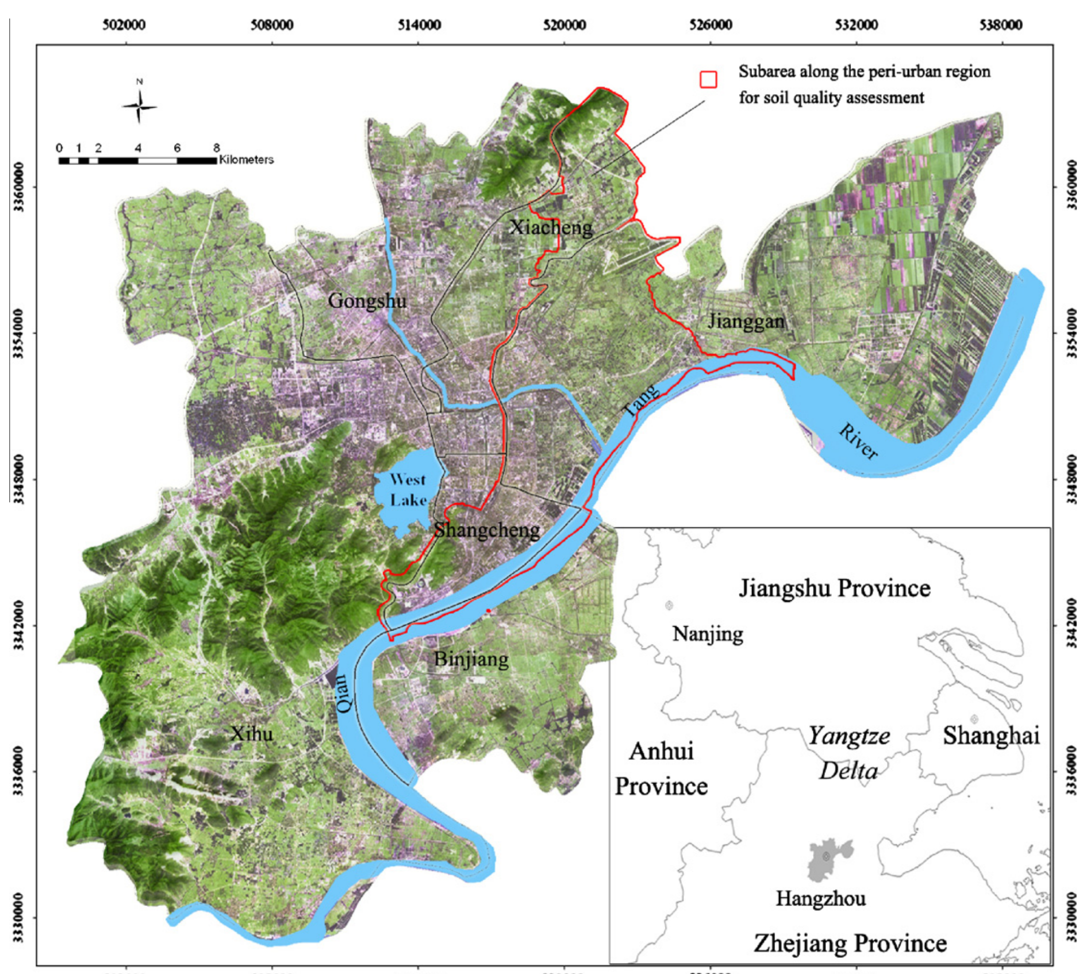


**Fig. 1.** Location of the study area in the Yangtze Delta, Eastern China.

countries. Hangzhou has been representative of coastal metropolises that are experiencing dramatic growth and restructuring.

*Data source and pre-processing*

*Data source*

In this study, four scenes of cloud-free SPOT images (1996-10 m spatial-resolution, 2000-20 m, 2003-10 m and 2006-10 m) were employed for conducting land use change analysis. The sequential dataset comprises of three sensors and are characterized by two spectral modes. Ancillary data mainly include: land use map derived from the National Detailed Land use Inventory (1996); color-composition aerial photograph (2000); digital orthorectified map (DOM) and IKONOS image; field survey data collected in 2003 and 2006 respectively; soil and fertility maps and related research reports from the National Detailed Soil Inventory (1984).

*Pre-processing*

Precise geometric corrections including image-to-image rectification and registration are the most important steps for multi-temporal land use change detection using remote sensing data. In this study a rigorous orthorectification method based on collinearity equation instead of conventional polynomial transformation was performed on the SPOT images to guarantee geometric fidelity and making it more consistent with other spatial data. All the images were rectified to a common UTM coordinate system based on 1:10,000 scale DOM. Consequently, fine geometric corrections were achieved for the images with RMS errors less than half pixel which underlay precise change detection procedures.

Soil and fertility maps (1:50,000 scale) were scanned and rectified to the same UTM coordinate geo system. Afterwards, the rectified maps were digitalized into vector format suitable for computer processing in GIS.

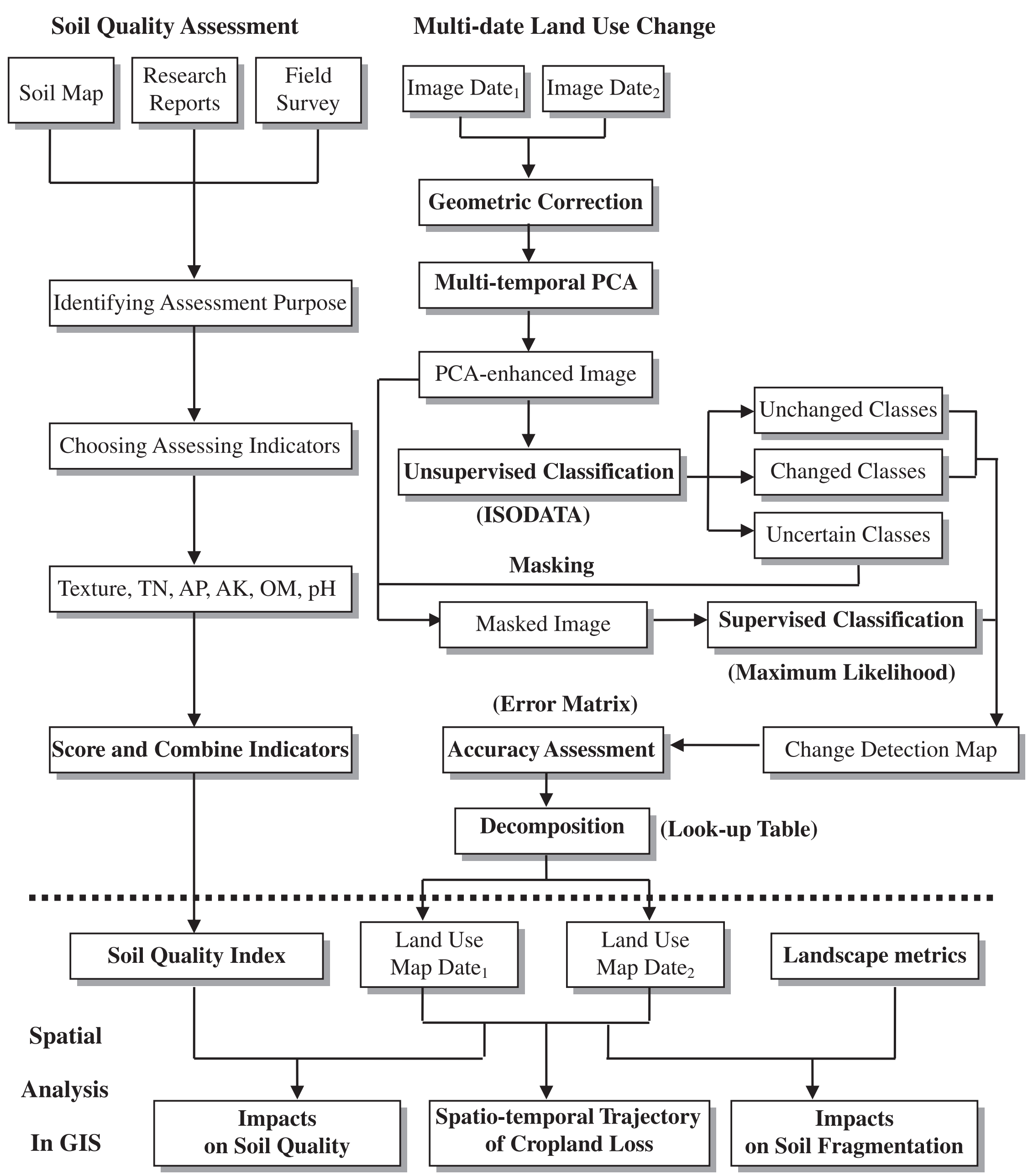


**Fig. 2.** The flowchart of the integrated method adopted in this study.

*Methods*

The integrated method adopted in this study has been illustrated in Fig. 2 and mainly includes three sections: land use change extraction, calculation of landscape metrics of fragmentation and soil quality assessment.

*Land use change extraction*

The proposed method combining principle component analysis (PCA) and hybrid classification to extract land use change information has been explicitly demonstrated in the flowchart (Fig. 2) which was an extension of a method successfully used in a tentative study (Deng, Wang, Li, Deng, & Qi, 2008). The main procedures that were used: (1) land use change information enhancement using PCA: PCA was first conducted on bi-temporal composite imagery to compress and highlight change into few components. (2) Land use change extraction using hybrid classification: the hybrid unsupervised-masking-supervised classification was sequentially carried out on the PCA-enhanced images to detect land use change. Detailed description of this method was shown in Fig. 2. Finally, total 12 land use and land use change types, adopt from a modified version of the Anderson land use/cover classification sys-

**Table 1**
Landscape metrics of fragmentation used in this study, after McGarigal, Cushman, Neel, and Ene (2002).

| Metrics | Description/calculation scheme | Unit | Range |
|---|---|---|---|
| PD—patch density | PD equals the number of cropland patches per 100 ha | Number per 100 ha | PD > 0 |
| MPS—mean patch size | MPS equals the average area of all cropland patches, divided by 100 | Square meter | MPS > 0 |
| LPI—largest patch index | LPI equals the percentage of the largest patch divided by total cropland area, multiplied by 100 | Percent | 0<LPI ⩽ 100 |
| AI—aggregation Index | AI equals the number of like adjacencies divided by the maximum possible number of like adjacencies, multiplied by 100 | Percent | 0 < AI ⩽ 100 |
| LSI—landscape shape index | LSI equals the total length of edge divided by the minimum length of class edge possible for a maximally aggregated class | None | LSI ⩾ 1 |

**Table 2**
The assessment system for soil quality index.

| Indicator | Score | | | | Weight (%) |
|---|---|---|---|---|---|
| | 4 | 3 | 2 | 1 | |
| Texture | Loam | Clay loam/sand loam | Light clay/sand clay | Heavy clay/sand | 25 |
| TN—total nitrogen (%) | >0.15 | 0.12–0.15 | 0.08–0.12 | <0.08 | 15 |
| AP—available phosphorus (mg/kg) | >40 | 30–40 | 15–30 | <15 | 15 |
| AK—available potassium (mg/kg) | >100 | 80–100 | 50–80 | <50 | 15 |
| pH | 6.5–7.5 | 5.5–6.5/7.5–7.8 | <5.5 | >7.8 | 10 |
| OM—organic matter (%) | 3.5 | 3.5–2.5 | 2.5–1.5 | <1.5 | 20 |

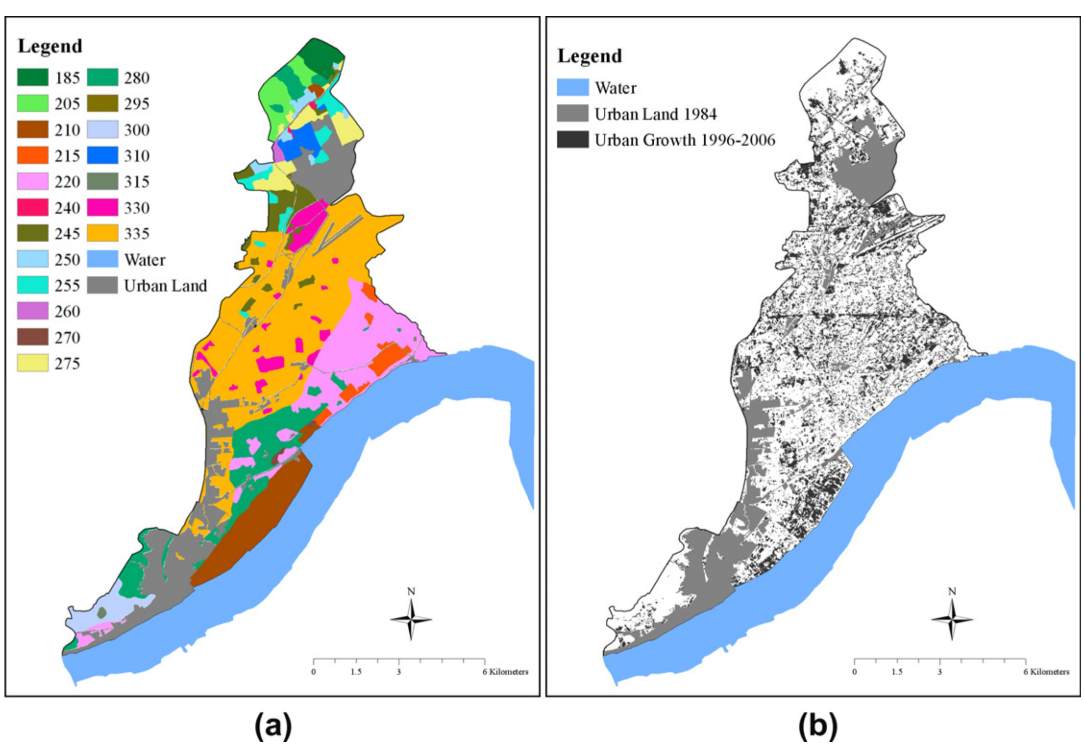


**Fig. 3.** The soil quality index (SQI) and extended urban area in the sub-area, 1996–2006.

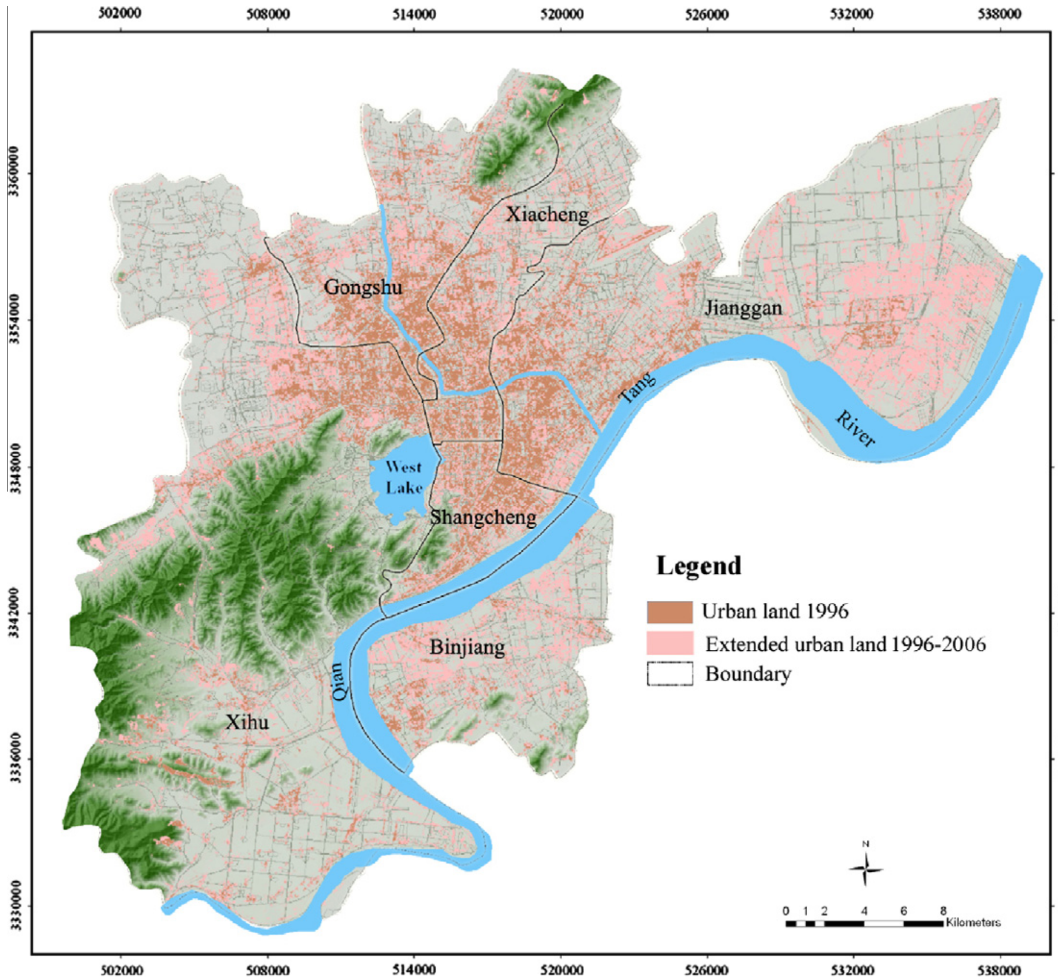


**Fig. 4.** Urban land extension map, 1996–2006.

tem, are detected and identified in this study. (3) Accuracy assessment for change detection: a quantitative accuracy assessment method which applied error matrix derived from classification and reference dataset was performed on these land use change maps respectively. A total of 930 reference points were selected to conduct the accuracy assessment. The overall accuracies exceed the minimum standard of 85% stipulated by the USGS classification scheme. Furthermore the Kappa coefficients also showed approving results. The overall accuracies are 88.39%, 90.43%, 92.58% for 1996–2000, 2000–2003, and 2003–2006 respectively. Similarly, the Kappa coefficients for the same period are found to be 087, 0.89, and 0.92. (4) Obtaining individual thematic land use map: land use change maps were respectively decomposed into two separate thematic land use maps which were taken as the inputs for further spatial analysis in GIS.

*Landscape metrics of fragmentation*

In order to examine the impacts of urbanization on cropland landscape pattern, this study focuses on the questions of landscape fragmentation which provides information on how urbanization breaks up larger cropland patches into smaller and complicated ones and, further shapes more isolated patterns. In practice, the ED and the MPS have been recommended as fragmentation indicators (Luck & Wu, 2002; Tyler & Peterson, 2004; Weng, 2007; Yu & Ng, 2006; Zhang, Shu, Wu, & Zhen, 2004b; Zhang, Zhang, Chen, White, & Li, 2004a). To address this focal question and comparability with previous studies, thereafter, a set of landscape metrics were specifically selected in this study with the aim for a comprehensive representation of the effects of urbanization on cropland at class level. These metrics were calculated by the public domain software FRAGSTATS 3.3 and used for detailed analysis of the spatio-temporal patterns of cropland change (Table 1).

*Soil quality index*

In this study, a sub-area covering five towns was selected as case study to undertake the soil quality assessment (Fig. 1). The placement of sub-area is equally spaced along the peri-urban region which has experienced dramatic urbanization process. In general, limiting factors for soil quality include climate, topography, soil properties and management measures (Zhang et al., 2007). However, the sub-area is located in Hang-Jia-Hu Plain which is characterized by flat and fertile land resource (Fig. 1). In fact, the climate and topographic conditions are also relatively uniform and the management measures of soil adopted the same pattern within study area. Thereby, soil properties are the main components in soil quality assessment and comparison, and the assessment's goal focuses on the soil fertility capacity. Once the purpose for the assessment is identified, soil quality indexing involves three main steps: (i) selection of appropriate indicators; (ii) transformation of indicator data into scores; and finally (iii) conversion of the indicator scores into an index (Karlen, Andrew, & Wienhold, 2004).

Due to data-related limitations, altogether six general indicators were selected for the soil quality assessment (Table 2). Gener-

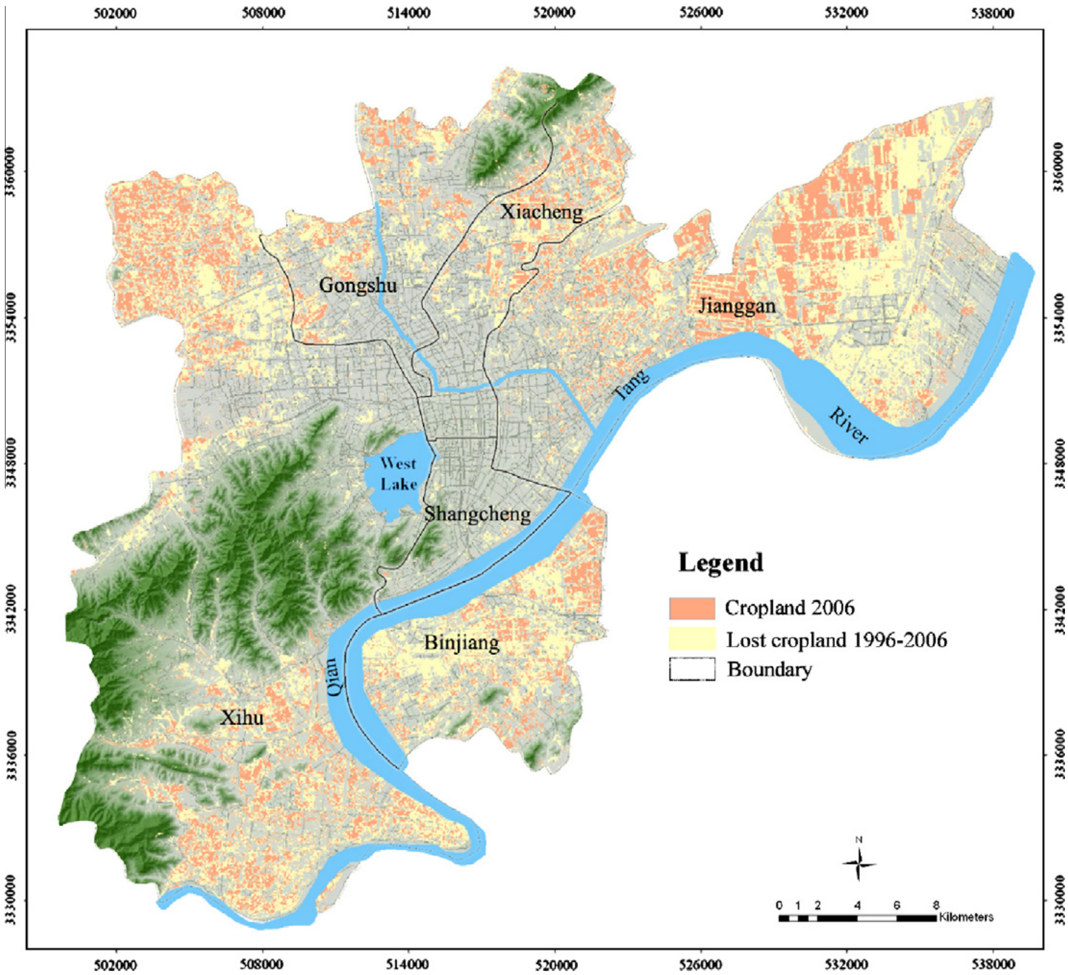


**Fig. 5.** Cropland loss map, 1996–2006.

**Table 3**
Land use conversion matrix from 1996 to 2000 (in hectares).

| 1996 | 2000 | | | | | 1996 Total |
|---|---|---|---|---|---|---|
| | Cropland | Orchard | Forest | Water | Urban Land | |
| Cropland | 26819.05 (80.06%) | 76.87 (0.23%) | | 1328.17 (3.96%) | 5275.91 (15.75%) | 33500.00 |
| Orchard | | 1699.67 (84.53%) | | | 311.14 (15.47%) | 2010.81 |
| Forest | | 446.63 (3.43%) | 12583.41 (96.57%) | | | 13030.04 |
| Water | | | | 10175.71 (89.97%) | 1134.92 (10.03%) | 11310.63 |
| Urban Land | | | | | 12108.09 (100%) | 12108.09 |
| 2000 Total | 26819.05 | 2223.17 | 12583.41 | 11503.88 | 18830.06 | 71959.57 |

ally, scoring and combining the indicators into indices for assessment is often based on expert opinion or accomplished with statistical procedures (Andrews & Carroll, 2001; Andrews, Karlen, & Mitchell, 2002; Doran & Parkin 1994; Zhang, Shu et al., 2004; Zhang, Zhang et al., 2004). However, the effects of some factors such as soil texture are not easily quantified by numeric equations, so that expert judgement is required, and the Delphi method is often used to produce a reliable measurement of judgements by a group of experts (Kangas, Alho, Kolehmainen, & Mononen, 1998; Marggraf, 2003; Richey, Mar, & Horth, 1985; Zhang, Shu et al., 2004; Zhang, Zhang et al., 2004). In this study, expert score ranking combining the Dephi method were adopted to quantify the scales and weights of each variable according to its contributions for soil productivity (Table 2). For reason that soil texture affects many other soil physical and chemical properties and also affects the availability of some soil nutrient for crop growth (Zhang, Shu et al., 2004; Zhang, Zhang et al., 2004), the highest weight was assigned to the variable of soil texture. A weighted additive system was then used to combine various variables to obtain the soil quality index and produce a soil quality distribution map using GIS (Fig. 3). Finally, the index was graded into four categories of scales according to the fertility capacity of the soil: I (300–335) = extremely good quality, II (260–295) = very good, III (220–255) = good, IV (185–215) = normal.

## Results and discussion

### *Spatio-temporal trajectory of cropland loss from 1996–2006*

After China's comprehensive urban reforms and open-door policy in the mid-1980s, Hangzhou has made great efforts to attract foreign and domestic investment, and was successful to kick start rapid urban development (Fig. 4). Since then, cropland has experienced arguably the most widespread and intensive loss (Fig. 5). The conversion matrix (Table 3) clearly indicates that, from 1996 to 2000, altogether 5275.91 ha of cropland were depleted for urban development, composing 78.49% of the total urban expansion during the 4-year's period. The annexation of six townships from suburban counties (Xiaoshan and Yuhang counties, respectively) in 1996 substantially increased the city's administrative area by 58.2%, and provided considerable impetus and extra space for further rampant urban sprawl. Cropland in suburban area was developed for urban expansion and relocation of industries from central districts and transformed into industrial, commercial, and residen-

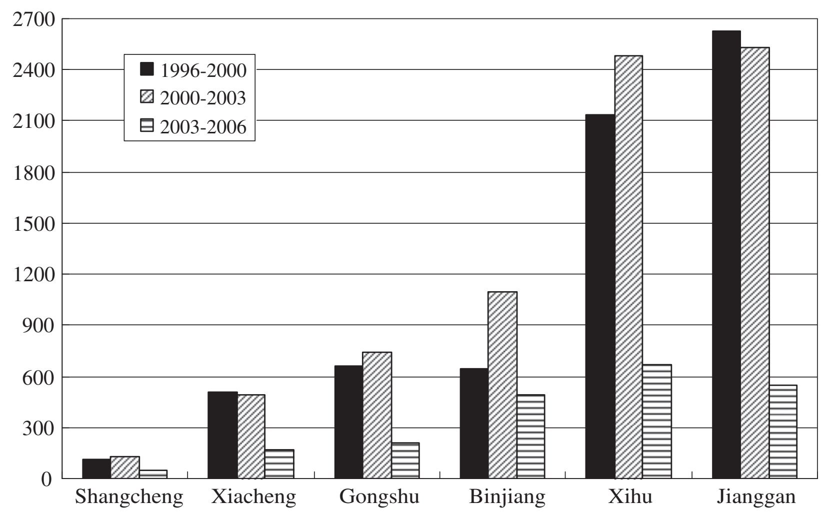


**Fig. 6.** Spatial occurrence of cropland loss of three periods (in hectares).

**Table 4**
Land use conversion matrix from 2000 to 2003 (in hectares).

| 2000 | 2003 | | | | | 2000 Total |
|---|---|---|---|---|---|---|
| | Cropland | Orchard | Forest | Water | Urban Land | |
| Cropland | 19347.00 (72.14%) | 314.34 (1.17%) | | 702.23 (2.62%) | 6455.48 (24.07%) | 26819.05 |
| Orchard | | 2064.49 (2.86%) | | | 158.68 (7.14%) | 2223.17 |
| Forest | | | 12532.83 (99.60%) | | 50.58 (0.40%) | 12583.41 |
| Water | | | | 11278.28 (98.04%) | 225.60 (1.96%) | 11503.88 |
| Urban Land | | | | | 18830.06 (100%) | 18830.06 |
| 2003 Total | 19347.00 | 2378.83 | 12532.83 | 11980.51 | 25720.40 | 71959.57 |

**Table 5**
Land use conversion matrix from 2003 to 2006 (in hectares).

| 2003 | 2006 | | | | | 2003 Total |
|---|---|---|---|---|---|---|
| | Cropland | Orchard | Forest | Water | Urban Land | |
| Cropland | 17205.53 (88.93%) | | | 362.71 (1.87%) | 1778.76 (9.19%) | 19347.00 |
| Orchard | | 2212.81 (93.02%) | | | 166.02 (6.98%) | 2378.83 |
| Forest | | | 12408.79 (%99.01) | | 124.04 (0.99%) | 12532.83 |
| Water | | | | 10572.81 (88.25%) | 1407.70 (11.75%) | 11980.51 |
| Urban Land | | | | | 25720.40 (100%) | 25720.40 |
| 2003 Total | 17205.53 | 2212.81 | 12408.79 | 10935.52 | 29196.92 | 71959.57 |

tial development areas. Another significant loss was the conversion from cropland to water (1328.17 ha) and a minor were converted to orchard (76.87 ha). These conversions can be ascribed to the restructuring agricultural configuration and market promotion because of better economic value and incomes from breeding aquatics and planting seeding tree compared to that of grain, which were also found in other economic-developed regions in China (Li & Yeh, 2004; Long, Tang, Li, & Heilig, 2007). Spatially speaking, major cropland loss occurred in Jianggan (2624.15 ha) and Xihu (2134.06 ha) districts, altogether accounting for 71.33% of the total lost area (Fig. 6). In fact, Hangzhou Economic and Technological Development Zone (ETDZ) and Industry Park were initially constructed within these two districts since 1990s. Meanwhile, due to the massive relocation of industry and rapid development of real estate, Gongshu and Binjiang districts also experienced cropland loss, reaching 656.92 and 641.34 ha respectively, altogether accounting for 19.43% of the total loss.

A similar pattern of cropland loss was found between 2000 and 2003, but the situation was more striking. As shown from Table 4, the depleted cropland dramatically reached 7472.05 ha of which 6455.48 ha or 78.89% were encroached for urban development. The lost cropland made up of about 93.69% of the increase in urban land. During this period, industrial land use has been further pushed towards newly developed areas, such as ETDZ, and many new commercial and residential areas have been constructed in both the old city districts and newly developed ones. Furthermore, the city has been experiencing an unprecedented boom in real estate, making it one of the most expensive places in China to live (Wei & Li, 2002). These factors have been combined to bring about cropland disappearance at a conspicuous scale over time. Meanwhile, there was a considerable decrease in the conversion from cropland to water (702.23 ha) and, by contrast, an increase in the conversion from cropland to orchard (314.34 ha). The spatial analysis further revealed that 40 ha of water and orchard converted to urban land in 2000–2003 were initially derived from cropland in 1996. With respect to spatial occurrence, the largest loss occurred in Jianggan (2531.88 ha) and Xihu (2484.13 ha) districts occupying 67.13% of the total loss (Fig. 6). However a notable increase in cropland loss (1095.35 ha) was identified in Binjiang district owing to the stimulus of "Development Over Qiangtan River Strategy" constituted by Hangzhou government in 2000. The incentive stratagem led to a flood of land development activities and speculation. In addition, considerable cropland loss (742.81 ha) was identified in Gongshu districts due to the massive residential development and relocation of industries in suburban areas.

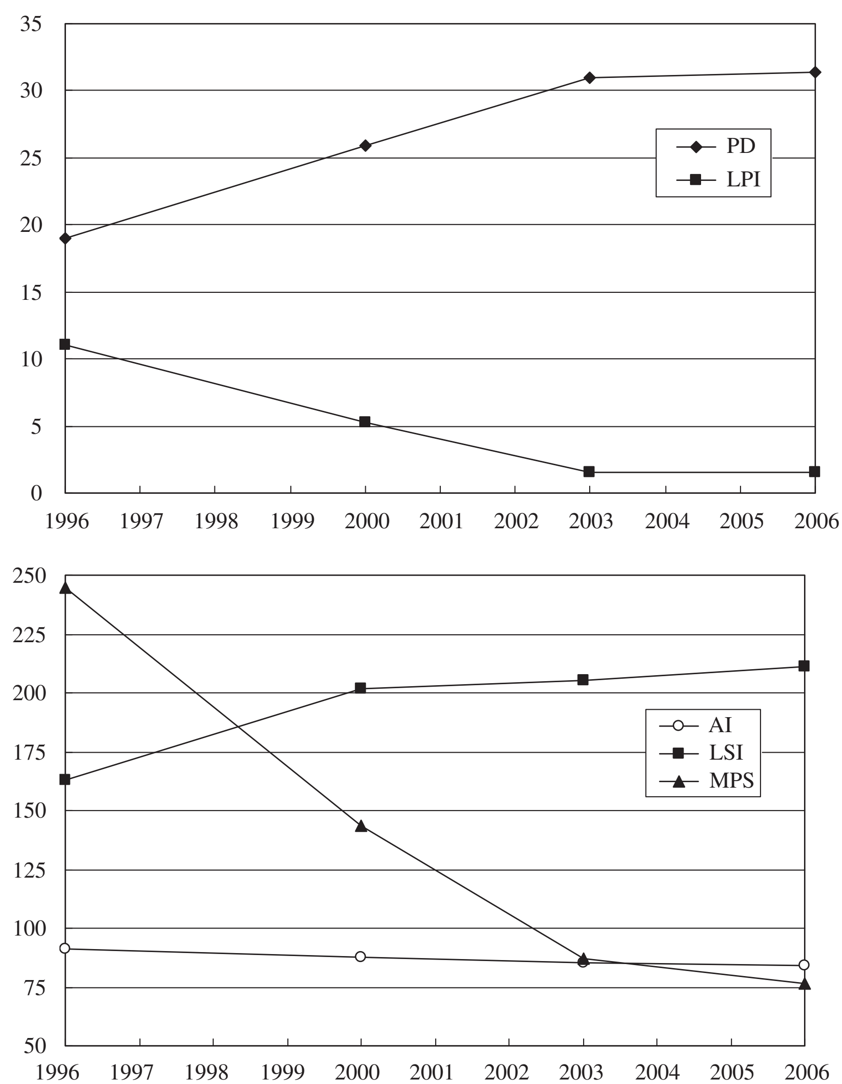


**Fig. 7.** Changes in landscape metrics of fragmentation at class level.

By 2003, urban growth and cropland loss dramatically exceeded the expectations of Hangzhou's urban planners and administrators, and easily surpassed the control targets set up by the planning departments of central and local governments. A series of laws and regulations concerning the protection of agricultural land, especially the Basic Farmland were imposed which put forward substantial constrains on the conversion of agricultural land to urban development. Consequently, cropland available for further rampant urban development in Hangzhou was significantly limited as reflected by a sharp decline in cropland-to-urban (1778.76 ha) and an increase in water-to-urban (1407.07 ha) from 2003 to 2006 (Table 5). The figures of cropland loss were only about one-forth of what occurred in the 2000–2003. Meantime, an obvious decrease in the conversion to water (362.71 ha) was also found from Table 5. However, 222.25 ha of water-to-urban and orchard-to-urban were inherited from cropland in 2000. Fig. 6 further indicates that the spatial occurrence of cropland loss exhibited the same pattern in which Jianggan, Xihu and Binjiang districts altogether accounted for 81.23% of the total areal loss.

*Impacts on fragmentation of cropland landscape*

As illustrated in Fig. 7, concomitant with the rapid urban expansion was a considerable increase in cropland patch density and decrease in MPS, especially during the periods of 1996–2000 and 2000–2003. Accompanying the enormous decline in cropland area, PD increased greatly from 19.02 to 31.35, in concert with about threefold decrease in MPS from 244.70 to 86.86. This illustrates an increasingly fragmented composition and dispersed distribution of cropland. The trend is further confirmed by the steep decline in LPS index from 11.04 to 1.57, reflecting the fact that dominant enclosed cropland patches with large area had been destroyed at a considerable scale by anthropological disturbance. Consequently, the cropland area was comprised of individual patches with large distance in between, and had a fairly diffused pattern, as is evidenced by AI metric. Along the obvious fragmentation process over time, dramatic land development divided cropland into smaller but complicated patches, as shown by the gradual increase in LSI, which actually hampered the cultivation management in fields. After the rush of cropland loss in the 1996–2000 and 2000–2003, PD, MPS and LPI changed slightly between 2003 and 2006, indicating that continued loss was concentrated on the small patches adjacent to urban land. This trend is in conjunction to the sharp decline in cropland loss in the time of 2003–2006 owing to improved management and planning activities. However, as evidenced by AI and LSI, the continual urban growth has still made cropland more fragmented and dispersed.

*Impacts on cropland soil quality*

As indicated from Fig. 8a, fertile soil types were the main land resource encroached for urbanization expansion. Of the increased urban land, 38.11% and 15.93% occurred in *Light loamy typic-dark-aquic cambosolos* and *Light loamy calcaric-ochric-aquic cambosols* respectively, which are the principal productive soil for vegetable growth in Hangzhou according to the reports of the 'Comprehensive Soil Survey' in 1985 and field survey. Fig. 8a further indicated that most of the eliminated soils were identified

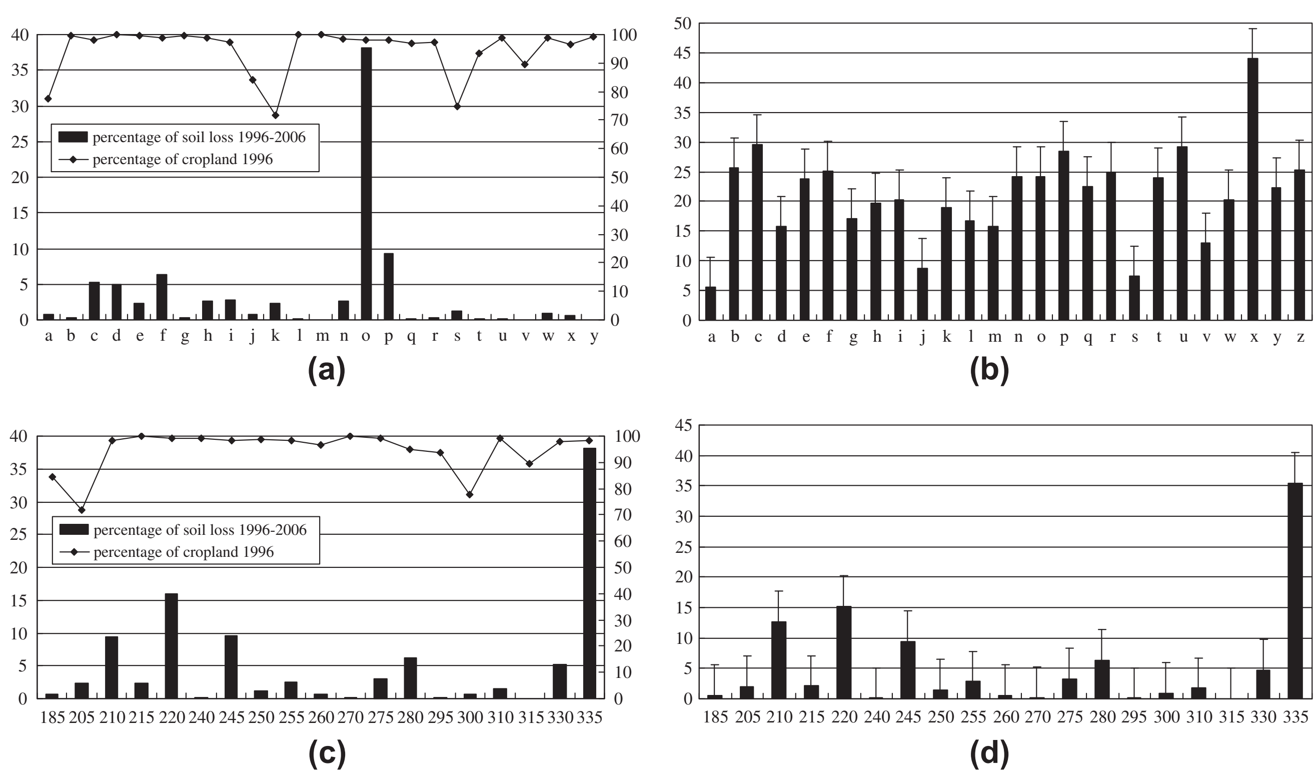


**Fig. 8.** Impacts of urban extension on soil types and SQI, 1996–2006. (a) area percentage of total soil loss and cropland for certain soil type; (b) percentage of total area for certain soil type; (c)-area percentage of total soil loss and cropland for certain SOI; (d) percentage of total area for certain SOI. (a – *waxy red soil*, b – *powdery-loamy paddy soil*, c – *Eutric fluvio-marine friable loamy soil*, d – *Eutric fluvio-aquic soil*, e – *strong capacity sea-beach soil with sandy potassium layer*, f – *free compacting flat sandy soil with a blue mud inter layer*, g – *blue silt-clayey paddy soil*, h – *powdery-loamy paddy soil with peaty potassium layer*, i – *free compacting flat sandy soil*, j – *gravel yellow soil*, k – *gravel gritty yellow red soil*, l – *Eutric fluvio-aquic soil with a peaty inter layer*, m – *paddy field on anthropic aggradated silty soil*, n – *paddy field on fluvio-marine yellow loam soil with yellow mottled subsoil*, o – *fluvio-marine yellow loam soil*, p – *paddy field on fluvio-marine yellow loam soil*, q – *Yellow soil*; r – *paddy field on yellowish red soil*, s – *gritty yellow red soil*, t – *paddy field on redeposit of gritty red soil*, u – *silt-clayey yellow mottled paddy soil*, v – *paddy field on calcareous redeposit of gritty red soil*, w – *powdery-loamy paddy soil with peaty inter layer*, x – *silt-clayey yellow mottled paddy soil with* seven *peaty inter layer*, y – *silt-clayey yellow mottled paddy soil with peaty potassium inter layer*, z – *strong capacity sea-beach soil*).

to be utilized as cropland in 1996 with the minimum of 71.68 and the maximum of 100 percentages. Moreover, certain soil types or unique soil unite such as *Light clay typic-Fe-accumulic-stagnic anthrosols* is in danger of disappearing because it has been deceased by 44.04% along with rapid urban extension, illustrated in Fig. 8b. Altogether other 15 types of soil has declined by more than 20%. The potential loss of entire soil mapping units, with their unique history of formation and biology, gives rise to the issue of the loss of biological diversity inherent in those soils (Imhoff, Lawrence, Stutzer, & Elvidge, 2003; Zhang et al., 2007).

Another concern raised by this study is the significant impact of rampant urbanization on soil quality. It was demonstrated from Fig. 8c and d that most of urban extension occurred in land with good soil quality. A considerable high proportion of fertile soil with SQI ratings I or II (43% and 29.06% respectively) was depleted spanning 10 years. Fig. 8c further showed that soil with best quality (SQI = 335) accounted for 82.56% of SQI rating I and 38.11% of total soil loss. More surprisingly, the greatest number of these changed soil initially belonged to cropland in 1996. Altogether 45.86% of the depleted cropland comprised of soil inherent in excellent soil quality with SQI rating I and 29.86% from soil SQI rating II.

## Conclusion

The presented land use change extraction method coupled with GIS has demonstrated its ability to provide comprehensive information on the direction, nature, rate and location of land use changes as a result of rapid urbanization. While the landscape metrics and soil quality assessment provide insights into the significance of impacts on ecosystem process and sustainable development.

As is elaborated in this study, rampant urban growth has brought about remarkable cropland loss and imposed great challenges on sustainable development. A total of 14013.69 ha (41.83%) cropland has been encroached into urban land, accounting for about 82% of the whole urban growth. In addition, a large number of cropland haven also been converted into water and orchard (1914.61 ha and 366.17 ha respectively), which can be ascribed to agricultural restructure and market promotion for better incomes. Spatio-temporal analysis indicates that cropland loss occurred at a notable scale in 1996–2000 and reached the peak in 2000–2003 and then underwent a sharp decline in 2003–2006. As for spatial occurrence, cropland loss concentrated in Jianggan, Xihu and Binjiang districts in consistent with the urban development planning. However, these dramatic changes have caused an increasingly fragmented composition and dispersed distribution of cropland landscape over time. As evidenced by the analysis of landscape metrics, the dominant enclosed cropland patches with large area has been divided into smaller and complicated ones with large distances in between and exhibited an actually diffused distribution. The findings derived from spatial analysis further revealed a severe competition between urban development and good quality soil in Hangzhou during the rapid urbanization process. These changes have executed permanent loss of cropland and imposed a threat to the sustainable development and food security. Although further analysis is needed to examine why most of the urban development occur on the valuable good quality soil before any conclusion can be drawn, one direct reason is the lack of rational urban planning and loose development control.

Though the data used in this paper cover a relatively small region and a limited temporal-dimension, the knowledge gained through the case study is crucial for seeking better understanding of a unique environmental concern and developing sustainable strategies of protecting cropland and ensuring food security concomitant with rapid urbanization process.

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