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# Urban landscape extraction and analysis in the mega-city of China's coastal regions using high-resolution satellite imagery: A case of Shanghai, China

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ABSTRACT

The analysis of urban land-cover classes and their spatial patterns are important problems in urban ecology, especially in ecologically fragile coastal areas. It is of great significance to those who optimize urban functional zones and are involved in urban planning management and sustainable development. High-resolution imagery has become an instrumental data source for detailed urban spatial pattern analysis, due to the complex structure of urban land covers made it difficult to achieve accurate and detailed information for urban landscape using medium or low-resolution images. In this study, based on China's GaoFen-1 (GF-1) high spatial resolution remote sensing images and a reference dataset, an information extraction technology based on a combination of pixel-, object-, and knowledge- based methods is developed to classify the land covers in urban built-up areas (BUAs) of Shanghai, China. The mapping and landscape pattern analysis of urban BUAs in Shanghai has been completed based on the results of land cover classification. The experimental results show that the overall accuracy and Kappa coefficients of the land-cover classification in Shanghai urban BUAs are 83.7% and 0.71, respectively, which provide effective and reliable data for spatial mapping and landscape pattern analysis. Through the landscape analysis of the classification results of land cover in Shanghai, the results demonstrated that not only is there a high degree of exploitation and utilization of land resources in Shanghai but also that the spatial distribution pattern of land cover types is reasonable, which indicates that its development is sustainable.

## 1. Introduction

Urbanization has promoted the formation of urban morphology and contributed to the rapid evolution of urban patterns (Liu et al., 2014). While urbanization is increasingly meeting the basic needs of human production, living, and services, it has led to increasingly fragmented landscapes and brought about the decline of ecological service functions, shortage of land resources, and other ecological problems (Pesaresi et al., 2015; Reynolds et al., 2017). Therefore, in-depth studies of urban land covers patterns are essential to promote sustainable urbanization.

Compared with other cities, urbanization of coastal regions should be given increased attention regarding sustainable development because cities in coastal region are categorized as urban fragile patterns (Cheng et al., 2016; Huang et al., 2017; Xian et al., 2018). Landscape pattern analysis is the basis for exploring the relationship between landscape pattern and ecological processes (Lin et al., 2016). Therefore, research on the landscape pattern of coastal cities is more conducive to the sustainable development of cities, land-use planning, and urban ecological protection.

A large number of urban landscape patterns have been studied using medium- or low-resolution remote sensing data such as Medium Resolution Imaging Spectroradiometer (MODIS) data (Schneider et al., 2010), DMSP/OLS nighttime light data from the Defense Meteorological Satellite Program (Ma et al., 2012; Zheng et al., 2016), and Landsat data (Fan et al., 2017a; Zhang et al., 2015b). However, the complex structure of diverse urban land covers made it difficult to achieve accurate and detailed land-cover classification for urban landscape analysis using medium or low-resolution images. Thus, high-resolution imagery has become an instrumental data source for detailed urban spatial pattern analysis due to its higher recognition accuracy and ability to identify more land type information.

With respect to the land-cover classification methods, although much progress has been achieved in recent years (Voltersen et al., 2014;

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**Table 1**
GF-1 images used in this study.

| Study area | City type | Sensor | Location[a] (°) | Date | Spatial resolution (m) | Image size (pixel) |
|---|---|---|---|---|---|---|
| Shanghai urban built-up area | Coastal city | GF1-PMS (panchromatic/multispectral) | E120.7/N31.1<br>E121.5/N30.8<br>E121.7/N30.8<br>E121.9/N31.4<br>E121.1/N30.7<br>E121.1/N31.0<br>E121.1/N31.0<br>E121.1/N31.3<br>E121.2/N31.6 | 2016 – 5-11<br>2016 – 8-1<br>2016 – 1-9<br>2016 – 1-9<br>2016 – 7-20<br>2016 – 5-11<br>2016 – 7-20<br>2016 – 5-11<br>2016 – 5-11 | 2/8 | 31968 × 23968 |

[a] Central longitude/latitude for GF1-PMS.

Yu et al., 2016), accurate land cover classification in urban built-up areas (BUAs) using high-resolution images continues to be a challenge. In previous studies, researchers have proposed a series of spatial and structural features, such as spectral index, shape, texture and morphological profiles, which improved the separability among spectrally similar objects, such as buildings, roads, and hardened ground (hardened ground refers to that inside or around a building, whose surface is typically cement, asphalt, masonry, or other impervious materials.) (Huang and Zhang, 2012; Ouzounis et al., 2012). Moreover, compared with using only a single feature, multi-feature combination can improve the dimensions of feature space and increase the separability of land-cover types (Zhang et al., 2017). Therefore, we apply multiple features to the classification because the multi-feature classification has more advantages than the single feature. In related studies, multi-feature based classification methods have often used a single classification strategy, such as pixel-based or object-based classification (Huang et al., 2014; Wilschut et al., 2013; Zhao et al., 2012). However, this method does not consider the characteristics of various types of features, such as spectral features belonging to pixel-based classification methods and shape features belonging to object-based classification methods (Keyport et al., 2018). Consequently, integrating pixel- and object-based image classification methods have been investigated in this study in order to fully explore the role of each feature in each land-cover type, thereby improving the interpretation efficacy of high-resolution imagery. On the other hand, the problems of “salt and pepper noise” and mixed land cover classes are the most common problems in the current classification strategy (Geiss and Taubenbock, 2015; Xin et al., 2014). In previous studies, manual correction is required for classification post-processing, which is labor-intensive and time-consuming, especially in urban BUAs. Therefore, we propose a knowledge-based post-processing method to reduce work in classification post-processing of urban BUAs.

The objectives of this paper address the key research questions for urban landscape extraction and analysis using high-resolution satellite imagery, concerning:

(1) conducting an urban land cover classification in an efficient way using high-resolution satellite imagery, and
(2) carrying out detailed landscape pattern analysis of the urban area of a coastal region based on the classification results of urban land cover extracted by high-resolution imagery.

The proposed methodology was conducted on Shanghai, a megacity located in China’s Coastal Region, in order to test the performance of the proposed method in extracting and analyzing urban landscape.

## 2. Study area and data sets

### 2.1. Study areas

In our study, a typical ecologically fragile megacity—Shanghai, China—was chosen for the analyzing the urban landscape pattern (He et al., 2017b; Yue et al., 2014). Shanghai (30°40′–31°53′N, 120°51′–122°12′E) is located in the Yangtze Delta region of south-eastern China, covering an area of 6341 $km^2$ and an urbanized area of 1644 $km^2$. It is one of China’s most important economic centers with a population of 24.3 million and a GDP of 2357 billion RMB in 2016 (Shanghai Municipal Bureau of Statistics, 2015). As the ecologically fragile city and the central city of the Yangtze River Delta urban agglomeration, Shanghai has been a popular location for urban land cover and landscape research (Fan et al., 2017b; Wang et al., 2017).

### 2.2. Data and preprocessing

#### 2.2.1. High-resolution remote sensing data

The GF-1 satellite is equipped with two high spatial resolution sensors cameras (GF1_PMS1 and GF1_PMS2) with 60 km width. The data acquired by the GF-1/PMS cameras includes one panchromatic band with a 2 m spatial resolution and four multispectral bands with an 8 m spatial resolution. The parameters of the data collected are shown in Table 1. The combination of two PMS cameras allows the sensor to feature high spatial resolution and wide imagery. In addition, the sensor has good lateral imaging capability and can observe a specific area with high frequency if needed during emergencies. The GF-1 satellite orbits at an altitude of approximately 645 km. The PMS cameras have a single width of approximately 30 km, and usually, the observations are made at a zenith angle of less than 10° or close to vertical observation. The PMS cameras have four visible/near infrared bands: common blue (band 1, 0.45–0.52 μm), green (band 2, 0.52–0.59 μm), red (band 3, 0.63–0.69 μm), near-infrared (band 4, 0.77–0.89 μm). Both cameras have a nearly identical spectral response function. In order to ensure complete coverage of the study area and better image quality, GaoFen-1 images with minimal cloud coverage and similar acquisition time were selected as much as possible in this study for urban land cover classification. Thus, 18 scenes (including multi-spectral and full-color) were selected for Shanghai, and the general information is listed in Table 1. Using GF-1 images of Shanghai with ortho-rectification based on a rational polynomial coefficients (RPCs) (using the RPC file in system) model (Teo, 2011), we fused images with the Gram-Schmidt spectral sharpening method and used relative normalization with the histogram matching method (Rahman et al., 2014). Due to the presence of clouds, overlapping cloudless area images instead of cloud area were used as much as possible. The imagery within the study areas was obtained by mosaicking and clipping by boundary data of urbanized areas in 2016 (boundary data from Section 2.2.2). Pre-processed GF-1 images of Shanghai are shown in Fig. 1(b).

#### 2.2.2. Reference data

Two databases served as a source of information for determining the boundaries of the study and road network extraction.

(1) The boundary of the urban BUA was updated in 2016 using GF-1