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Urban development and landscape change in the Yangtze River Delta region in China
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ABSTRACT
The impact of large-scale urban development on land resources has long been debated by urban planners and designers. This study investigated the extent to which different urban characteristics are associated with land-cover change. The Yangtze River Delta region in China, forming one of the largest sprawling urban landscapes among the regions around the world, was chosen for the study area. Spatial analysis and multiple regression methods were applied to empirically investigate the pattern of resource sites lost to urban development in the area between the 1950s and 2017. The results showed that contrary to the widespread notion that large-sized cities are predominantly responsible for a region’s environmental degradation, city size was not a significant factor in determining the rate of resource loss. Large-sized cities gained their populations with far lesser impacts on land than small-sized cities and towns if normalized to the same number of populations. One explanation for the diminishing effect of city size on land-cover change relates to the degree of spatial dispersion of urban development and local differences in social valuation of diversified lands by cities.

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1. Introduction: urban development impacts on Chinese landscape

Urban development and sprawl on the edges of existing cities is a spatial phenomenon that has transformed many urban regions around the world. An outward expansion of urban land includes complex dynamics, but it is most clearly represented by the transformation of land cover and the emergence of large built structure through urban development. The process involves the fragmentation of farmlands, forests, and rural settlements in the short run, followed by long-term changes in the composition of urban blocks, street patterns, transport infrastructure, households, and types of employment. In China, beginning in the early 1950s and particularly over the last thirty years, a socio-economic pull towards cities has created an agglomeration of large urban regions. Of about thirty megacities with more than 10 million populations around the world, six are located in China, including cities like Shanghai, Beijing, Chongqing, Guangzhou, Shenzhen, and Tianjin.

Three urban regions in China present hot spots of intensive urban development and extensive urban sprawl in China. Jing-Jin-Ji, also known as Beijing-Tianjin-Hebei Metropolitan Region is located on the northeast coast of China. The Pearl River Delta region has nine cities like Guangzhou in Guangdong Province and is planned to extend its economic link with nine surrounding provinces and two areas of Hong Kong and Macau, which will eventually form the ‘Pan-Pearl River Delta (9 + 2)’ region. The other is the Yangtze River Delta region, having some 65 cities and 1,525 towns including Shanghai, Jiangsu, and Zhejiang Provinces (National Bureau of Statistics of China 2017). In the region, the clustering of urban settlement has led to the formation of one of the world’s largest sprawling urban landscapes, converting a vast amount of urban-rural fringe lands to urban uses (Yang et al. 2018).

During the urbanization process of the regions, one social fear was that the extent of urban development and its impact on the productive land capacity had gone too far. For instance, a political backlash against inappropriate land conversions developed, followed by the State Council’s veto of unauthorized land conversion in the 1990s (U.S. Embassy Beijing 1997). Also, local governments stopped development approvals to limit the nation’s development-zone fever (kaifaqu). This is at least partly because the fertile lands in China’s coastal areas have been degraded rapidly to a point where modification of the current path of development was inevitable.

More broadly, this perception was associated with the so-called ‘over-exploitation syndrome,’ involving a negative chain of population growth, consumptive...
land uses, and increased pressure on lands for resource extraction and infrastructural development (Ehrlich and Holdren 1971; Lambin and Geist 2006). This indicates that large-sized cities facing rapid urbanization may be associated with more intensive land-cover change. According to this position, one could anticipate the intensity of land change to be positively associated with the size of a city. For instance, Liu et al. (2005) identified a positive correlation between urban population growth, economic development, and the expansion of 13 large-sized cities’ urban land in China. But this positive relationship does not seem to be a universal law. A preliminary examination of remote-sensed images of China, for example, suggests that a large amount of landscape transformation has also occurred away from large cities. This could indicate that population growth or city size may not be a singularly determining factor of land-cover change (Stern 2004; Sherbinin et al. 2007; Kim and Rowe 2012).

2. Policy measures against excessive urban agglomeration

In the Chinese context, particularly since the 1980s, the State emerged as key decision makers in the allocation of land-use rights for urban development. While urbanization took place at a number of different scales over the period, a set of counter-measures against excessive urban development arose to prevent the loss of non-urban lands. Some of these policy measures were: (i) limiting the supply of developable lands through an annual quota for the allocation of urban use, which initiated in the 1980s, (ii) tightening controls over building permits and project financing, (iii) providing incentives for maintaining and reclaiming certain resource lands, such as prime agricultural lands and nature reserves (Lin and Ho 2003; Wang et al. 2007; Kim and Rowe 2013), and (iv) limiting the number of migrants against settling down in already crowded metropolitan cities through demolition of illegal houses and eviction. Additionally, as previously discussed in Kim and Rowe (2012), the unmitigated loss of resource sites was deliberately avoided in some places to protect land as a means of social safety nets for the residents.

In China, the national and local urban policies have attempted to control the size of cities, often favoring the development of small-sized cities and towns compared to very large cities (Buck 1981; Kwok 1987; Fan 1988). For instance, controlling city population size has long been part of a national planning agenda. ‘Control large-sized cities’ growth, reasonably develop medium-sized cities, and rigorously encourage the development of small-sized cities’ was promulgated in the National Conference on Urban Planning and approved in the State Council in 1980. While larger cities were often designated as growth centers under urban reform, the growth of overly large cities was curtailed as a forward-looking means of preventing diseconomies of urban agglomeration for the purpose of mitigating pressures on transport, housing, schools, and local healthcare systems. The measures were sometimes taken under the name of fixing ‘big-city disease’ or ‘beautifying’ the cities. For instance, Shanghai and Beijing governments announced their population caps at about 25 and 23 million, respectively, by the year of 2020 to define the upper limit of city size (Roxburgh 2018).

Within the context, there is a research gap about how the development of different cities has affected the nearby landscape in China from a longitudinal perspective. Here, the study is a preliminary attempt to identify the relationships between urban characteristics and the loss of valuable land resources. For the purpose, China’s Yangtze River Delta region was empirically investigated, primarily focusing on the loss of environmental resource sites—measured as the rate of resource loss (% year$^{-1}$)—lost to urban development between the 1950s and the present. Through this, whether some urban indicators such as city population size and the pattern of urban sprawl have contributed to the disappearance of valuable resource sites were examined. The main focus was the cover of land, not its use, although they are closely related. Land-use patterns – such as cultivation, logging, and transportation – are shaped by a host of socio-economic and political motives. How and where those uses manifest and change over time affects land-cover patterns – such as the clearing of sites, the partial modification of land, and the wholesale conversion of a site into urban land – which conversely influences the surrounding land uses.

3. Research methods

3.1. The study area and data collection

The Yangtze River Delta region is comprised of large flatlands and mountainous areas located between the Yangtze River (also referred to as ‘Changjiang’) and the sea. The area is a triangle-shaped deltaic region having one of the largest urban conurbations in the world, including major cities like Shanghai, Suzhou, Hangzhou, Nanjing, and Ningbo. To estimate long-term landscape change—especially the rate of resource site losses in the study area—a series of land-cover maps were created for the years of 1950, 1979, 2000, and 2017. For the purpose, multiple spatial data sources were collected including Landsat remote-sensed images, digitized historic maps, land-use planning documents, and high-resolution aerial photographs derived from Google Earth Pro.
specify land covers across the study area, GIS-based visual interpretation of land cover was carried out using remote-sensed images acquired from the US Geological Survey (USGS), such as the Landsat Orthorectified Multispectral Scanner (MSS, 1979), Enhanced Thematic Mapper Plus (ETM+, 2001), and Landsat 8 OLI/TIRS (2017). Following the standard method of processing the images, the software Multispec was used to conduct supervised classification of the images based on the land-cover classes as proposed in Anderson et al. (1976).

Since the remote-sensed images did not cover all of the maps comprising the study area, high-resolution aerial images and 450 land-use planning documents from the Yenching/Pusey Library at Harvard University and the Seoul National University Library were collected. The urbanized area of cities and towns, as well as their boundaries, were digitized across the years based on the GIS databases from the Harvard Geospatial Library, the China Data Center at the University of Michigan, and other sources like Taihu Basin Authority (2000), Hsieh (1973), and documents from the China Geological Survey. Once the digitized land-cover data sets were generated, the region’s land surface was subdivided into grids with a size of 1 km². For each grid, a dominant land-cover type out of the standard classes was recorded by years. The size of a grid cell was chosen based on the coarse resolution of digitized maps. Then, the amount of environmental resource sites lost to urban sprawl was estimated by overlapping the locations of resource sites with cumulative urban area between 1950 and 2017. In the study, environmental resource sites were defined as natural or human-modified land capital, such as forests, agricultural lands for cash crops, freshwater bodies, and wetlands, that produces ecological services and environmental benefits.

3.2. Defining samples

For analyses, 41 cities and 56 towns (total N = 97) in the region were chosen (Figure 1). The boundaries between cities could be clearly distinguished from an aerial photo. For the towns, those with the largest areas of urban land were given higher priority for selection. Another selection criterion was the distance between towns and cities. A minimum distance of 10 km between the edges of the urban area was kept during the process to avoid the selection of too

many samples from a limited area. To compare the relationships between urban and environmental variables by cities, stratified sampling was conducted. Since the total number of cities and towns was very high, the entire population was divided into subgroups by population sizes, then samples were randomly and proportionally selected from the different subgroups. Since administrative boundaries showed great variations in the proportion of urban and non-urban lands to a point that inter-city comparison was nearly impossible, this study attempted to draw a sampling boundary using some consistent standards applicable to different-sized cities and towns.

Drawing the boundaries was a confusing task. Definitional approaches of urban boundaries differed by researchers. For instance, in one of the most comprehensive reviews on the world’s urban fringes, Simon (2008) defined a diameter of 30–50 km near cities to be a boundary of urban fringes. The definition, however, was not applicable to the towns in the study area, since they were located in close proximity to nearby cities and other towns. Unlike Simon, Heimlich and Anderson (2001) described in their US Department of Agriculture report that urban fringe could be characterized by the presence of the low-density development of houses, roads, and commercial buildings within metropolitan regions. Within the similar vein, Wolman et al. (2005) defined the urban fringes of US cities in a more systematic manner. They combined both an urbanized center of cities and their nearby census blocks to define the urban boundary of a city. Here, based on the literature review, two criteria were applied to define the sampling boundaries: (i) areas with a population density >1,000 people per km$^2$, measured based on the Population Grid Data (1 km$^2$) and; (ii) if delineating a boundary based on the population density was difficult owing to the close proximity between cities, major geographic barriers like mountain ridges were used as a division line between samples; if no major barriers were found, the relative population sizes of cities were used to draw a line between samples. For instance, the city of Wuxi’s urban population and Suzhou’s was 2.4 million, meaning that the ratio was almost 1:1 (Figure 2). Thus, the mid-point of a line connecting the centers of two cities was used to define the boundary. The above definitions of population density and relative division between cities provided a reasonable basis for delineating the sampling boundaries of cities with both urban and non-urban lands.

3.3. Analytical methods

The relationship between city size and resource losses was tested by using exploratory spatial analyses and the regression method. First, for exploratory analyses, the scaling-function method proposed by researchers like Bettencourt et al. (2007), (2010) was adopted. Here, the method used city population size ($P_t$) as an indicator of city size (at time $t$) that explains various urban and environmental indicators of a city within the sampling boundary. The formula is expressed as: $Y_t = Y_0 P_t^\beta$, where $Y_t$ denotes a measure of urban and environmental indicators of a city within the sampling boundary; $P_t$ denotes city population size; $Y_0$ is a constant, and $\beta$ is an exponent. In the study, among many indicators, $Y_t$ was defined as the log of the area of resource sites lost to urban sprawl within each sampling boundary.

Second, a multiple linear regression method was applied to estimate the effects of different urban and environmental indicators on resource losses in the region. The indicators included city population size,
the spatial patterns of urban expansion, economic conditions, and other environmental variables. All variables were tested for multicollinearity using the variance inflation factor (VIF). In the regression analysis, five different models were tested. The first model included only urban indicators, such as city size, the rate of population growth, and measures of urban sprawl patterns like Moran’s I and the degree of elongation. Subsequent models included additional explanatory variables. The second model controlled for multiple environmental variables. The third and fourth models included the density of industrial enterprises and sewer lines as a proxy for basic infrastructure, as well as the density of roads as a measure of the intensity of urban construction and transport infrastructure in Model 4. The last model had a full list of urban, environmental, economic, and institutional variables. Detailed description of the major variables used in the regression model is as follows.

**Measure of resource loss (dependent variable)**

Satellite-derived estimates of the annual rate of the environmental resource sites lost to urban sprawl during 1950–2017 (% year\(^{-1}\)) were used for the measure (Figure 3). The rate was calculated based on the changes in the total area of four resource sites within each sampling boundary. A 1 km\(^2\) grid cell was classified as ‘resource loss’ if the cell used to be dominated by one of the resources and then is converted into urban built-up land over the periods. Conversion between non-urban land covers was not accounted for in the estimation.

**Measure of city size**

City population size was defined as the log-transformed urban population of cities and towns in the study area. The log scale was chosen because the distribution of city size in the region was highly skewed, with a far higher number of small cities and towns than larger cities. On average, larger cities are expected to have lost a larger area of resource sites during the urban sprawl process than smaller cities. Also, the rise of consumer income in larger cities is likely to spur more consumptive land development, as per-capita floor area for housing and commercial uses may increase accordingly. Nonetheless, previous studies found that increases in city size are also associated with increasing returns to scale, e.g., wealth creation and industrial production, and economies of urban size, e.g., less per-capita area of the infrastructural surface.

**Measures of urban sprawl patterns**

Previous studies showed that the patterns of urban sprawl and neighborhood characteristics are often associated with negative environmental impacts, including increased vulnerability to environmental hazards and land consumption (Ewing 1997; Kim and Ryu 2015). The prevalence of low-density, sprawled, and inefficient land uses in a newly urbanized region was noted as one of the problems in China. Among multiple ways of quantifying urban patterns, Tsai (2005) examined the validity of Moran’s I. His study illuminated the possibility that the Moran’s I index can distinguish compact urban patterns from scattered patterns. By definition, Moran’s I is one of the indices measuring the degree of dependence of spatial events. The index is bounded between \(-1\) (= dispersed) and 1 (= clustered), after row-standardization is performed. Finally, this study also included several environmental, economic and development, and disaster-related variables that were identified as potentially significant in other research.

4. Results

4.1. Weak, non-linear city-size effects on resource losses

The results of the scaling-function method indicated that city population size presented a fairly weak, statistically insignificant correlation with the log-transformed amount of resource loss between the 1950s and 2017 (Figure 4). The log of resource loss (Y) was
positively associated with the log of city size (N), although the relationship was not statistically significant (adjusted $R^2 = 0.35$, $\beta = 0.61 \pm 0.18$). A scaling exponent value of this formula (=$\beta$) was much smaller than 1, meaning that resource loss is a saturating function of city size due to a mechanism of economies of scale and the effect of additional population growth decreases as the size of a city increases. This potentially indicated that increases in the size of small cities may have greater negative impacts on nearby resource sites than the growth of larger cities. Since city size showed a positive but non-linear relationship with the amount of resource losses, the result might be referred to as land-saving effects of an increase in city size. Additionally, it is probable that large-sized cities and their peripheral land resources may have benefited from the gradual reduction in the amount of lost resources as city size grows.

The relationship between city size and resource loss was further examined by accounting for the same unit of population growth. The premise is that, if a city with large population consumes a lesser amount of resource lands than a small-sized city, then this land-saving mechanism needs to be tested in terms of the same population growth over different types of landscapes. The results showed that the growth of additional 1,000 populations in smaller cities was associated with greater loss of all four types of land resources (Figure 5). In the same vein, large-sized cities gained their populations with far lesser impacts on land than small cities.

One explanation for the diminishing impact of city size on land might be that a large city absorbed a significant portion of population growth within the inner-city area. As already discussed by MIT economist William Wheaton (1982), urban development does not necessarily occur from the center outwards. Developments may follow a reverse direction – from the periphery to the inner-city area – such as with high-density redevelopments of dilapidated housing in old residential districts and new construction on formerly vacant parcels near the city center. Yet, within the Chinese context, densification of inner-city areas may be a marginal, if not negligible, factor, because it would be an over-estimation to assume that more buildings were built through inner-city redevelopments than through the development of urban periphery.

A more likely explanation is that large-sized cities have been more responsive to the growing demands for diversified land uses. Local governments in the region, ranging from municipal governments to town governments and various land users, may attempt to take advantage of land resources in a way that serves the interest of their community. The motivation toward the development of land having limited community benefits and without losing the diversified arrangement of environmental resources seems to be stronger in mid to large-sized cities. For instance, in Shanghai and Suzhou, an agglomeration of service industries, high-tech jobs, government bureaus, wealthy residents, and tourism industries led to an escalated social valuation for historic gardens, open spaces, amenity sites, green spaces, clean water sources, and specialized farmlands for the production of vegetables, fruits, and organic products. Securing multiple land resources may create long-term returns, making cities more attractive and adaptable to future increases in resource demands.
Unlike those cities with diversified land covers, another group of cities saw large-scale resource losses. It seems that this process has been more frequent in small-sized cities and towns. In this study, three cities – Nantong (including Qidong, Rugao, and Tongzhou), Liyang, and Jintan – were investigated as examples. These cities share some similarities. By 1990, they were small cities according to the Chinese city-size classification system, although Nantong was slightly larger in terms of population than the upper limit of the small-size category. Also, these cities experienced fairly rapid population growth: 11.6% per year in Jintain during 1995–2005, 6.26% in Nantong during 1990–2005, 6.2% in Liyang during 1990–2005, and 4.9% in Rugao during 1995–2005. These population bursts were strongly associated with the local governments’ strong focus on the provision of urban built-up land. According to the Nantong Land-Use Master Plan (2006–2020), about 77.5% of the city’s total land-use conversions from 1986 and 2020 will be comprised of decreases in agricultural land use (= 40.5%) and increases in urban land use (= 37.0%). Similarly, 83.5% of Liyang’s and nearly 90% of Jintan’s land-use change will be comprised of these two types of monotonic land-cover conversion. Of course, a large-scale loss of cultivated land per se may not pose a serious problem to cities as long as the food supply can be sustained from distant rural areas. But the more fundamental issue here is whether the resultant urban pattern really serves the diverse demands and anticipated economic returns envisioned by the residents, landowners, and local government officials. This critique was raised by urban planners in Nantong. The notion was that there has been a relatively low investment in service-related industries in terms of the use of developable land and uncompetitive high-tech parks were overly developed. Additionally, too many scattered towns and village settlements have expanded in such a way that per-capita use of urban land became very high (Nantong Municipal Government 2011, Article 11).

4.2. Results of regression analyses

City population size

As shown in the results of the multiple regression models (Table 1), city size was not significantly associated with the rate of resource loss when multiple variables were controlled for. In the first two models, large city size seemed to potentially be one of the factors causing rapid resource losses at the 1%
Table 1. Results of the multiple regression models.

<table>
<thead>
<tr>
<th>Regression models</th>
<th>Urban indicators only</th>
<th>Urban indicators with environmental variables</th>
<th>Urban indicators with infrastructural development variables</th>
<th>All of the variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban indicators</td>
<td>Log of city population size in 2015 0.144*** (0.0451)</td>
<td>0.129*** (0.0428)</td>
<td>0.077 (0.052)</td>
<td>0.069 (0.0465)</td>
</tr>
<tr>
<td>Rate of population growth (%)</td>
<td>0.007 (0.0007)</td>
<td>0.0007 (0.00649)</td>
<td>0.0034 (0.00631)</td>
<td>0.00038 (0.00681)</td>
</tr>
<tr>
<td>Sprawl pattern (Moran’s I)</td>
<td>−3.346** (1.664)</td>
<td>−3.197* (1.678)</td>
<td>−2.942* (1.698)</td>
<td>−3.451** (1.648)</td>
</tr>
<tr>
<td>Sprawl pattern (quadratic form of Moran’s I)</td>
<td>6.439** (3.026)</td>
<td>6.520** (3.045)</td>
<td>7.345** (3.277)</td>
<td>5.938* (3.161)</td>
</tr>
<tr>
<td>Elongation of an urban area</td>
<td>−0.097 (0.187)</td>
<td>−0.108 (0.198)</td>
<td>−0.088 (0.196)</td>
<td>−0.019 (0.201)</td>
</tr>
<tr>
<td>Environmental variables</td>
<td>Soil condition (1 = clay) 0.254** (0.103)</td>
<td>0.252** (0.102)</td>
<td>0.191* (0.101)</td>
<td>0.315** (0.128)</td>
</tr>
<tr>
<td></td>
<td>Soil condition (1 = silt)</td>
<td>0.293*** (0.086)</td>
<td>0.297*** (0.0837)</td>
<td>0.235*** (0.121)</td>
</tr>
<tr>
<td></td>
<td>Average slope of land (degree)</td>
<td>−0.0397*** (0.0138)</td>
<td>−0.0375*** (0.0132)</td>
<td>−0.0319*** (0.0124)</td>
</tr>
<tr>
<td></td>
<td>Presence of mining or logging sites (1 = exist)</td>
<td>0.0935 (0.0103)</td>
<td>0.125 (0.0103)</td>
<td>0.0574 (0.117)</td>
</tr>
<tr>
<td></td>
<td>Number of amenity sites (within 3 hr travel distance)</td>
<td>−0.00641 (0.00627)</td>
<td>−0.00702 (0.00694)</td>
<td>−0.0125* (0.00679)</td>
</tr>
<tr>
<td>Economic and other variables</td>
<td>Per-capita GDP 3.8210(10)** (0.0000016)</td>
<td>4.2310(10)** (0.0000016)</td>
<td>3.8210(10)** (0.0000016)</td>
<td>−0.00116 (0.00241)</td>
</tr>
<tr>
<td></td>
<td>Density of large-sized enterprises</td>
<td>−0.00116 (0.00241)</td>
<td>0.0073 (0.0000016)</td>
<td>0.000319 (0.00268)</td>
</tr>
<tr>
<td></td>
<td>Density of major roads (km/km²)</td>
<td>0.667* (0.0125)</td>
<td>0.014 (0.0113)</td>
<td>0.007 (0.00949)</td>
</tr>
<tr>
<td></td>
<td>Density of sewer lines (km/km²)</td>
<td>0.014 (0.0125)</td>
<td>0.001 (0.00051)</td>
<td>0.000 (0.00051)</td>
</tr>
<tr>
<td></td>
<td>Air pollution (NO2)</td>
<td>7.802* (4.338)</td>
<td>4.2310(10)** (0.0000016)</td>
<td>4.2310(10)** (0.0000016)</td>
</tr>
<tr>
<td></td>
<td>Earthquake events (1 = earthquake)</td>
<td>−0.953*** (0.358)</td>
<td>−0.927*** (0.390)</td>
<td>−0.429 (0.551)</td>
</tr>
<tr>
<td>Intercept</td>
<td>−0.953*** (0.358)</td>
<td>−0.927*** (0.390)</td>
<td>−0.429 (0.551)</td>
<td>−0.507 (0.505)</td>
</tr>
<tr>
<td>Adj. R-Square</td>
<td>0.239</td>
<td>0.266</td>
<td>0.284</td>
<td>0.344</td>
</tr>
</tbody>
</table>

Note: The correlation coefficients of listed variables were calculated using OLS regression analysis. The dependent variable is the variance in the rate of resource losses during 1950–2017. In the table, heteroskedastic consistent standard errors are shown in parentheses and the significance level is as follows: *p < 0.10, **p < 0.05, ***p < 0.01.
Therefore, in general, increases in city size result in more clustered urban patterns. However, this trend may be reversed, or Moran’s I can be lowered during the process of urbanization, if continuous urban development is discouraged for various reasons. For example, dense villages on the urban fringes or socially valued heritage sites can be resistant to urban development, since the estimated return of urban lands may not be obviously higher than the current social and economic value of the land in the long run. This relationship is illustrated in a U-shaped graph between Moran’s I and the rate of resource loss (Figure 6). We can infer that the curve shape indicates that the same amount of urban development may have amplified negative effects on resources if its spatial pattern is associated with both ends of the convex curve in the graph. A major implication of the result is that a substantial amount of resource loss that has occurred in the region was associated with the outward spread of small-sized urban places, especially near towns, as well as fairly large places and metropolitan cities. The growth of small cities and towns has involved a highly dispersed urban development pattern that has a greater environmental impact on the land cover than large-sized cities in per-capita terms.

No statistically meaningful relationship was found between elongated urban patterns and resource losses. Highly elongated urban forms, with W: L ratio >2, were commonly found in the towns located along the waterways between Taihu Lake and Shanghai. Zhouhuangzhen, for instance, used to be a town stretched out along Beishihe Stream near Dianshanhu Lake in Suzhou. In the mid-1980s, its administrative status was elevated into a designated town and transportation accessibility from and to large-sized cities like Shanghai and Suzhou dramatically improved. These factors, along with the town's well-preserved architectural heritage dating back to the Ming and Qing periods, and urban residents’ growing demands for vacation houses, have led to the full-scale occupation of the town’s eastern part by urban settlements (Figure 7). Among cities in the region, Yizheng showed the most elongated spread pattern, parallel to multiple expressways, Yangtze River, and a

![Figure 6. Scatter plot of the Moran’s I coefficients and the rate of resource loss, 1950–2017.](image1)

![Figure 7. Urban spread pattern in Zhouhuangzhen, 2002–2017. A: Zhouhuangzhen in 2002, B: Newly developed housing district in 2012, C: Zhouhuangzhen in 2017.](image2)
planned railway line. These examples show that the degree of elongation of a city’s spread pattern is largely determined by landforms, waterbodies, and infrastructure constraints, and thus cannot be an accurate measure of the urban impact on land cover.

Rate of urban population growth
Urban population growth per se was not a good indicator of the rate of resource losses in the region. Although the coefficients were positive, none were statistically significant in the regression models. Even when towns were dropped to avoid possible measurement errors, the relationship between the population growth of cities and resource loss was not straightforward. For instance, cities like Jurong, Kunshan, Jingjiang, Zhangjiagang, and Jintan, which showed the highest population growth rates (7.6% or higher per annum) in the region, did not show a linear trend relating to resource losses. These results were unanticipated since a migration of people to a place and their land-use practice is often considered one of the major drivers of land-cover change in developing regions around the world.

The Yangtze River Delta region may deviate from this causal chain between population growth and land-cover change because neither the subsistence needs of villagers nor the economic activities of large-scale enterprises have driven the process of urban development. For instance, the above-mentioned regional cities with rapidly growing populations were largely mid to small-sized county-level cities that benefited from their comparative advantage in industrial production, sometimes playing a part in regional supply chains. These cities remained relatively small county seats until the early 1980s; then, they were designated county-level cities after the mid-1980s, as was the case with Zhangjiagang in 1986 and Kunshan in 1989 (Li 1997; Wei 2002). The local governments acted not only as a reformer of formerly backward economies, but also as a powerful agent for attracting foreign investment, accumulating capital for urban development, and negotiating with the central government for more favorable resource allocation. Therefore, population growth was not a precursor of land-cover change in the cities but was more of a consequence of the state-guided capital investment in the built environment.

Environmental and amenity variables
Basic environmental characteristics largely served as significant predictor variables of resource loss in the region. This indicates that despite a highly dispersed pattern of resource loss, the basic environmental characteristics of a site do matter when local governments and land developers make their decisions. For instance, soil texture and the slope of land were significant across all regression models. The region’s clay and silt soils are comprised of non-calcareous, alluvial rice paddy soils, as well as podzolic and young red soils, which are generally very productive with high water-holding capacity (Buck 1937). The positive coefficients of both clay and silt soil mean that the areas are likely to be associated with relatively rapid land-cover change than areas of sandy soil, like the eastern coastal area near Nantong. The negative coefficient of the average slope of land indicated that steeper sites, in general, have been less vulnerable to rapid land-cover change.

The number of recreational amenity sites, e.g., nature reserves, national parks, UNESCO World Heritage sites, and national or provincial scenic areas, were negatively associated with the rate of resource losses at a 5% significance level (Model 5). The coefficient can be interpreted as: a city with 10 amenity sites within 3-h travel distances was expected to show a lower rate of resource loss by 0.16% per year than a city without any amenity sites. This rate is not very high, but its cumulative impact on the land cover over many years may be substantial.

Economic variables
Per-capita GDP was positively associated with the rate of resource losses at the 5% significance level. The results indicated that if a city’s average per-capita GDP is assumed to increase from 35,107 yuan to 57,187 yuan – a leap from the regional average to the GDP of the regional-level city of Hangzhou – the annual rate of resource loss is likely to increase by 9.3%, holding all other variables constant. A general trend can be deduced from the results that wealthier cities are likely to have converted resource sites into urban land more rapidly and extensively. This outcome is consistent with environmental economists’ research indicating that economic growth, especially if led by resource-intensive manufacturing sectors, requires a large input of materials and land resources. Nonetheless, another group of studies about the Environmental Kuznets Curve Hypothesis argues that this relationship is not always linear. According to them, there was little evidence that economic growth leads to proportionate degradation of the environment in the mid to long run. In this study, both trends seem to be present. For instance, the correlation between economic growth and a high rate of resource loss is found in the lower part of the curve. However, in the upper part of 50,000 yuan or higher per-capita GDP, this relationship is not clearly predictable from the data as shown in the quadratic fit graph.

5. Discussion
The research presented the results of spatial analyses and the regression models of different variables that may explain the pattern of resource losses in China’s Yangtze River Delta region. The region’s resource sites
showed a large-scale reduction over the past sixty years. Unlike some concerns over large-sized cities’ negative impact on the environmental degradation, urban sprawl around both large and very small cities showed similar urban effect associated with resource loss. When normalized by the same population, the negative impacts of the growth of small-sized cities on lands were more significant. This outcome is due partly to the fact that city population size is not a singularly meaningful indicator of how quickly a city’s urban land expands for a long period of time, i.e., an increase in city population size is not positively associated with a higher rate of urban sprawl. Another factor is the presence of the diminishing impact of city population size on the loss of land resources. Explaining why large-sized cities have consumed less resource lands in per-capita terms during the urbanization process seems to involve multiple narratives: local governments’ responsiveness to the rising social valuation for diversified environmental resources may be one reason, as shown in cities like Shanghai, Suzhou, and Nanjing.

Another factor might be small-sized cities’ fundamental limitations for carefully managing urban growth. The limitations may involve multiple factors, such as relatively weak administrative foundations for protecting public benefits like lands, limited human resources for environmental protection, high up-front investment in the provision of infrastructure for striking a balance between development and preservation, and increasingly high competition for attracting industries and investment. Facing rare opportunities for rapid economic growth and the escalation of the political status of a city or a town, small-sized cities have replaced valuable resource sites with urban lands.

One of the major findings of this study is that large spatial variations of resource loss do exist. Put simply, defining a few places primarily responsible for the region’s resource degradation was difficult. Scattered towns and small cities have contributed to the loss of a substantial amount of resource sites, with equivalent degradation effects as those of large-sized cities when the same proportion of the land area is compared. Thus, two extreme sides about the environmental impacts of urbanization – largest cities cause the largest problems or urban effects on the environment happen at random locations – do not seem to be supported by the study results. Multiple regression models also back up this conclusion. The variable of city population size was not significant in association with the rate of resource loss when multiple variables were controlled for. The results, along with the presence of decreasing urban effects on resource cover as city size increases, indicate that the scattered distribution and sprawl of small-sized cities and towns may lead to much greater environmental degradation than the growth of regional-level cities.

Why does a causal chain of population growth, extensive urban development, and rapid land-cover change in large-sized cities often not exist? One explanation might be that a local government of a city that was large in its initial state systematically attempts to avoid missed opportunities that are obtainable from diversifying land resources during the urban growth process. In other words, a green space in Shanghai or Nanjing may generate appreciable social and economic values, which is perceived differently compared to the same green space located a small town. For instance, Shanghai diversified its drinking water sources to include the new QingcaoSHA Reservoir in the Yangtze River Estuary and to protect the city’s original water intake points along the Huangpu River; Nanjing utilized its geographic diversity so that the city’s cultural artifacts are coordinated with nearby scenic amenities and agricultural production sites. Also, some places near large cities have substantially increased their agricultural production capacity and promoted local tourism at the same time, as exemplified in DongshanZhen of Suzhou. On the other hand, small-sized cities like Liyang and Jintan, as well as numerous remote towns have focused on the monotonic land conversion from farmlands to industrial production units and roads. While it is too early to judge the success and failure of this land conversion practice, this may result in a host of problems in the long run, such as: (i) too many uncompetitive high-tech parks and industrial ventures are subsidized by local governments; (ii) infrastructural developments sprawled out substantially to serve dispersed places; (iii) environmental degradation from scattered urban places takes its toll on the cumulative wealth of the region, ranging from increased costs of clean water supplies to diminished disaster-prevention capability of coastal areas during flood or storm surge events.

As the effect of additional population growth decreases as city sizes increase, two urban policies may contribute to the environmental protection of the Yangtze River Delta region. One is to reasonably shift development opportunities from excessively scattered rural places to mid to large-sized cities in suitable areas for urbanization. Disconnected urban areas to the south of Nanjing, scattered developable sites between Wuxi and Changzhou, high-amenity pocket areas between Suzhou and Kunshan, and underdeveloped plains near the border of Anhui and Zhejiang Provinces, for instance, might serve as promising sites for future urban development. Yet, some areas near large cities may need to be preserved for the sake of multiple environmental benefits, e.g., east-coastal areas of Pudong in Shanghai that are prone to severe environmental hazards or the southern part of Wuxi that is directly connected with large-scale aquaculture sites and freshwater bodies. The benefits may include the
reduced conflicts between multiple priorities such as food production, biodiversity protection, and keeping a variety of resource covers within urban regions.

Another potentially useful urban policy is to redirect the land-consumptive, redundant urban sprawl of small towns. Clearly, a vast number of towns and townships in China are important places of economic activities and social liveliness for their residents. However, a sizeable number of towns in the region are following a similar industrialization model—investing in a few profitable industries and expecting to generate instant economic gains. Despite the hype driven by the success story of this model, such as in the cases of Kunshan or Zhangjiagang, transferring the model to the other parts of towns in the country competing with each other based on the same developmental strategies, will not be easy. Increasingly high labor costs and living expenses, the lack of social services that attract mid to high-income families, and rather slow changes in local politics are impediments to the growth of small towns. Nonetheless, there are some opportunities as well. As already demonstrated in the region, merging two or more towns to form a larger administrative mass will be one of the promising planning directions. Additionally, functional divergence among towns may also be accelerated, despite the questioning of territorial differentiation between the ‘town’ as opposed to ‘urban’ and ‘peri-urban’ as discussed by Davis (2016). A town with innovative technology or key resources for advanced industries may be able to boost its economic growth, while nearby towns and townships may become more dependent on the growing town from economic and demographic perspectives. Whatever path is chosen, the early phase of a group of towns’ administrative merging or physical transformation to a larger place would be the most cost-effective moment for the careful planning of urban land, infrastructure, housing, and valuable resource in order to lead to desirable consequences in the long run.

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