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The Livable Urban Landscape: GIS and Remote Sensing Extracted Land Use Assessment for Urban Livability in Changchun Proper, China

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The livable urban landscape: GIS and remote sensing extracted land use assessment for urban livability in Changchun Proper, China

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ABSTRACT

Despite the popularity of the term urban livability, it is often used by different groups under different circumstances. A broader understanding of urban livability is that it concerns the quality of life in any human living environment. The World Health Organization, among many others, suggests a four-dimension assessment system based on the concepts of convenience, amenity, health and safety that can be used to evaluate any cities' potential livability. Following this proposal, the current study taps into the power of GIS and Remote Sensing technologies to generate a set of urban livability evaluating indicators via extracted land use information. Using the city proper of Changchun, Jilin Province of China as an example, the study extracts fifteen individual land use indicators from topographic maps and a remote sensing imagery. A principal component analysis-based approach was used to build an urban livability index with the fifteen indicators. Furthermore, with detailed examination of relevant studies, national documents and local fieldwork, this research also establishes potential benchmark values for all fifteen livability evaluating indicators for comparison purposes. Results suggest that slightly more than half of Changchun's city proper is above the livability benchmark in the framework of the current study. Residents' access to parks and open spaces is a major lagging factor for the city proper's livability. The study provides an alternative of quantifiable and verifiable approach for sustainable urban planning, especially from a land use policy perspective.

1. Introduction

Urbanization in China has experienced rapid development during the past decades. While rapid urbanization brought tremendous changes on urban landscape, scholars also observe the increase of urban pollution, traffic congestion, shrinking public services and aging infrastructure in Chinese cities (Fang et al., 2016; Liu, 2018; Liu et al., 2014; Yu et al., 2014; Zhan et al., 2018). These so-called "urban diseases" (Fang and Yu, 2016) have adversely impacted on city residents' daily lives across the entire city. Under such circumstances, both the Chinese government and scholars attempt to address urban livability issues in recent years (Zhan et al., 2018).

Although used liberally, the term urban livability often lacks a consensus of what exactly it refers to. Kashef (2016) summarizes broadly three different aspects of urban livability research, namely, from the design literature, the planning literature, and the popular media and global ranking literature, and advocates for an interdisciplinary understanding that potentially considers all aspects of urban livability. Such suggestions, though conceptually appealing, often lack practical operability. Urban planners and other urban science practitioners, on the other hand, carefully consider urban livability as a balanced and harmonious mode of economic, social, cultural, land use and environmental development in cities (Asgarzadeh et al., 2012; Flores et al., 1998; Kazemi et al., 2018; Liu et al., 2014). A livable city, from the urban planning and land use perspective, is a city that possesses an adequate set of good inhabitable conditions (both natural and cultural) and reasonable land use patterns that meet the needs of the residents in material and spiritual life (Chen et al., 2016; Dumbaugh, 2005; Li and Guo, 2006b; Liu et al., 2017; Mesimaki et al., 2017; Zhan et al., 2018) and support both the city's and its residents' long term development needs.

The origin of urban livability has a long history. The ancient Chinese ideology of "nature and humanity" recognizes that harmonious relationships between human and nature is critical for ideal living. In the west, the thought of livability can be traced back to ancient Greece where philosophers often pondered the relationships between human

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activities and their impacts on the nature (Gideon, 1998). In 1961, American reporter Jane Jacobs proposed to create more suitable and livable cities for human habitation in her book *The Death and Life of Great American Cities* (Jacobs, 2002), which is often seen as the modern research origin of urban livability. In 1976, the world health organization (WHO) put forward the notion of livability that refers to the living environment of “safety, health, convenience and amenity” (Higasa, 1977). In the late 1980s, enhanced awareness of ecological environment construction, increased understanding of the importance of appropriate land use planning and policy in urban development, worldwide consensus for sustainable development and newly emerged urban safety issues have made urban livability the focus of recent studies in human and social development (Beames et al., 2018; Chen et al., 2016; Dumbaugh, 2005; Leach et al., 2017; Liu et al., 2017; Liu, 2018; Newman, 1999; Paul and Sen, 2018; Tan and Hamid, 2014; van Kamp et al., 2003).

China, as one of the fastest urbanizing countries in the contemporary world, is confronted with a struggle of improving the quality of urban environment while in the meantime maintaining its rapid economic development (Fang and Yu, 2016; Liu et al., 2018). Urban livability in China has attracted general attention since Wu and colleagues put forward the concept in their book *Science of Habitat Environment* (Wu, 1997). *Science of Habitat Environment* is centered on constructing “pleasant settlements” and establishes the scientific foundation of livable urban research and practices. Based on Ding (2005) and Dong and Yang (2009)’s studies, livable city was initially proposed in order to attract and retain multinational corporations, and later it has become an important reason for the government to implement sustainable urban development strategies (Beames et al., 2018; Dumbaugh, 2005; Flores et al., 1998). With the growing understanding of livable cities, many cities in China began to pay attention to the concept of urban livability and integrate it as one of the goals for sustainable urban development. In the 15th Chapter of the *National New Urbanization Planning (2014–2020)* issued by the State Council of China in March 2014, it is specifically proposed that China’s new-type urbanization and urban development will strive to optimize the spatial organization and management patterns of cities in order to promote efficient land use practices for the construction of a more livable urban environment. Various agencies and organizations also have carried out the appraisal and rating of urban livability in various cities in China (Fu, 2013; Gu et al., 2007; Li and Guo, 2006a; Liu et al., 2017; Zhan et al., 2018; Zhang, 2007; Zhang et al., 2006). These research and relevant activities signal that urban livability is now becoming one of the top priorities of urban development in China. Deep understanding of the concept of urban livability and its implementation in different cities could provide strong support for sustainable urban land use policies especially in today’s rapidly urbanizing China (Liu et al., 2014).

Many studies of urban livability focus on the selection of livable indexes that quantify livable conditions. These indexes are often obtained from data of social statistics or satisfaction questionnaire which could be difficult to update in real time (Asami, 2001; de Sa and Ardern, 2014; Gideon, 1998; Jiang et al., 2004; Klopp and Petretta, 2017; Leach et al., 2017; Li and Guo, 2006a; Lynch and Mosbah, 2017; Paul and Sen, 2018; Shafer et al., 2000; Zhang, 2007) and might not be reproduceable when the research shifts to other locations. In this study, instead of relying on statistical yearbooks or field surveys, we aim to develop an alternative set of indicators relying on geographic information analysis (GIS analysis) and remote sensing information process. The individual pixel of the remote sensing image is our basic unit to investigate urban livability. Indicators generated in such a way have the potential to match spatial location relatively accurately and be updated more frequently (Chrysochoou et al., 2012; Fu, 2013). We didn’t include socioeconomic indicators in the current study since we intended to explore urban livability at the pixel level, though by no means did we regard urban socioeconomic factors as irrelevant to urban livability.

In addition, other than relying on subject weighting of individual indicators’ weights as in some livability ranking studies, such as the Mercer Quality of Life Index, or the Economist Intelligence Unit’s (EIU) Global Livability Rankings (Kashef, 2016; Shafer et al., 2000), this study attempts a data exploration approach by applying a principal component analysis-based method to generate objective weights for individual indicators to evaluate their contribution to urban livability at the pixel level. The current study contributes to the literature of land use policy studies by applying GIS and remote sensing technologies in urban livability data acquisition and developing a novel PCA-based method to process the data for a potentially more reliable urban livability evaluation framework. The current study of assessing urban livability via GIS and remote sensing might provide an alternative approach for the evaluation of sustainable urban land use practices in China and promotion of China’s new-type urbanization development.

The study takes Changchun, Jilin Province in the northeast of China as the study area and attempts to evaluate its urban livability from the standpoints of urban convenience, amenity, health and safety as proposed by the World Health Organization (Higasa, 1977). The evaluation is based on indictors acquired from a remote sensing image and various topographic maps through GIS analysis at the pixel level. Following this introduction section, we introduce the study area, the city proper of Changchun City, the GIS and remote sensing data processing procedure, and the principal component analysis-based method used for urban livability assessment and individual indicator contribution evaluation. The study then proposes a set of livable indicators derived from topographic maps and remote sensing image. In the fourth section, the study presents the results from the analysis and evaluates urban livability of Changchun based on the standards and criteria developed in the *Livable City Scientific Evaluation Criteria* proposed by the Ministry of Construction of the People’s Republic of China (PRC, M.o.C.o.t., 2002). We conclude the study in the fifth section.

2. Data and methods

2.1. Study area

Changchun, the capital city of Jilin Province, is the political, economic, cultural and transportation center of Jilin Province, China. The total administrative area of Changchun is 20,604 km^2 and the built-up area of the city is 660.19 km^2. Changchun is the ninth largest city in China. It is the center of the Northeast-Asia Economic Cycle (Fig. 1). As the economic center of Jilin Province, Changchun has developed rapidly since the early 1980s. In 2014, Changchun’s gross domestic product (GDP) reached $861.12 billion RMB Yuan and per capita disposable income reached $11,335.85 RMB Yuan. On the other hand, the city is also gradually suffering from a series of “urban diseases”, namely, traffic congestion, environmental pollution, and increasing pressure on the city’s infrastructure, among other issues. To achieve various goals of sustainable urban development, the city is in pressing need to provide a variety of high-quality services for all aspects of life and improve its infrastructure and service functions. Regarding such needs, understanding and enhancing the city’s livability are of particular interest for not just the urban development and planning scholars and the local governments, but also local residents. In this study, we attempt to establish a set of livability indicators using a remote sensing image and various topographic maps for Changchun and focus on Changchun’s city proper (instead of the entire built-up area due largely to data consolidation and collection considerations), which borders north on the northern ring road, south on 102th national highway, west on western 4th ring road and east on eastern ring road (Fig. 1).

2.2. GIS and remote sensing data processing

Topographic maps contain rich information of elevation, various surface features and landforms, which have profound impact on urban transportation and house construction, two critical aspects that impact

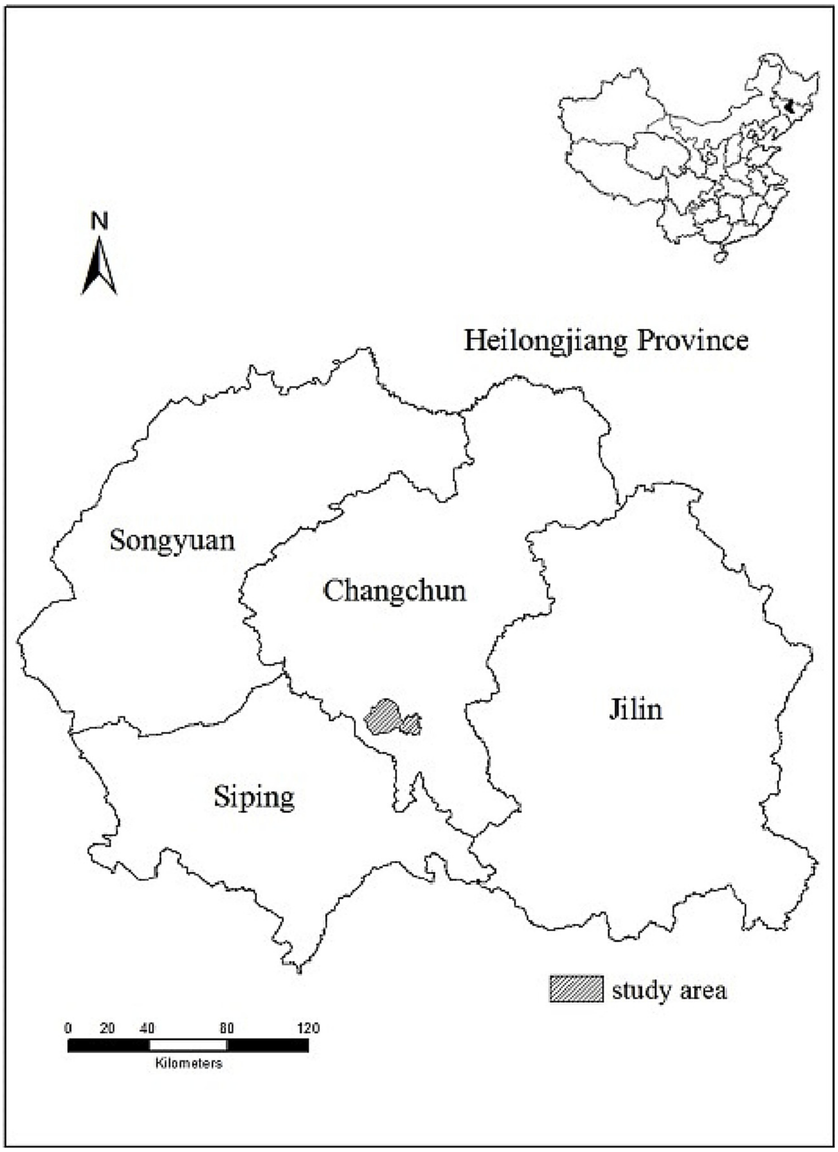

Fig. 1. Location of Changchun and the study area.

on urban livability. It is an indispensable basic data source in many livability studies (Gideon, 1998). Fourteen topographic maps with scale of 1:10000 were obtained and preprocessed in ArcGIS® to generate the landscape related indicators. All topographic maps are in Beijing Geodetic Coordinate System with Huanghai Vertical Datum 1956 and Krassovsky Ellipsoid and Guass-Kruger Projection.

Except for topographic maps, an Advanced Land Observation Satellite (ALOS) image taken in July 2014 was obtained as well. Remote sensing images, especially high-resolution ones, have the capability to provide detailed and frequently updated information of land use and land cover for various urban studies (Leong and Roderick, 2015; Ma et al., 2016; Shahtahmassebi et al., 2018; Wu and Murray, 2003). The image includes 4 bands (wavelength in 0.42–0.5 μm, 0.52–0.6 μm, 0.61–0.69 μm, and 0.76–0.89 μm) with a spatial resolution of 10 m. The image was projected and carefully resampled to match that of the topographic maps (Fu, 2013).

The topographic maps are rasterized to extract the indicators needed in evaluation of urban livability. Vector map rasterization is to delineate grid cells of a unified spatial reference and equal size based on the spatial location. Since the raster data contains precise spatial positional and relevant attribute information within regular grid cells, using existing raster cells (pixels) as our basic analytical spatial units might prove to be more operable and reasonable than using other arbitrarily defined spatial units. On the other hand, using pixels as the basic analytical spatial units also means that socioeconomic data that are usually collected based on administrative units might not be appropriate to be included in the study due to scale difference (the pixel used in this study has a spatial resolution of 10 m).

In the process of information extraction, rasterizing the topographic maps enables us to obtain landscape, landform, land use and elevation information. The topographic maps were rasterized to have the same spatial resolution as the ALOS remote sensing image used in this study. After the rasterization, there are 3054444 grid cells in our study area.

2.3. *The framework of urban livability indicator system*

Using indicators as basic understanding units and indicator systems as comprehensive evaluation tools has long been applied and discussed in various studies (see Yu et al. (2014) for a detailed discussion). When establishing an indicator system, there are a few grand rules for selecting indicators that we shall follow (Yu et al., 2014). First, the indicators should objectively and scientifically reflect the various aspects of urban livability. Second, the indicators should be selected hierarchically, so that different levels of indicators reflect different levels of urban livability, yet higher level indicators include lower level ones. Third, the lowest level indicators should be measurable and comparable from a quantitative perspective so that any quantification and statistical analysis are possible. Last, the data for the indicators shall be possible to obtain. This last rule is very important since no matter how prominent the indicator system is, it would be pointless from an analytical perspective if the data for the indicators could not be obtained.

As for livability assessment, though many global and local ranking systems based on a variety of different criteria are available (Kashef, 2016; Mesimaki et al., 2017; van Kamp et al., 2003; Zhan et al., 2018), there are no internationally accepted evaluation criteria. On the other hand, the living environment concept of “convenience, amenity, health and safety” proposed by WHO in the 1970s is an important basis for the evaluation of urban livability. Many scholars, especially scholars in China, often adopt the concept as a starting point in urban livability studies (Chen et al., 2016; Dong and Yang, 2009; Fu, 2013; Gu et al., 2007; Li and Guo, 2006a; Zhang, 2007; Zhang et al., 2006). In the study of urban livability of Changchun’s city proper, we also take the concepts of “convenience, amenity, health and safety” as our starting point. In addition, we further refer to the livable indexes proposed by Zhang and Chinese Ministry of Construction (Zhang et al., 2006) to construct our indicator system. Details follow.

2.3.1. Convenience category

Convenience means that people living in the city can enjoy a convenient life style. Specifically, indicators in this category will cover the fact that residents of a city should be able to use various facilities of the city conveniently (higher accessibility to those facilities). These facilities include daily public transportation facilities (that meet the residents’ mobility requirements), shopping malls, entertainment and educational facilities (that meet the residents’ daily needs of procurement, entertainment and education).

2.3.2. Amenity category

Amenity means that a city or the residential areas of a city has the necessary infrastructure or places that their residents can feel comfort and pleasure within. These include accessibility to places with pleasant natural amenity and satisfactory social amenity. Pleasant natural amenity refers to the beautiful and enjoyable natural landscapes; while satisfactory social amenity refers to the human landscapes within and around a city or the residential areas of a city that improve residents’ feeling of entertainment and individual development.

2.3.3. Health category

Health means that a city or the residential areas of a city can provide a healthy living environment to their residents. In particular, residents shall be able to enjoy clean water and clean air and be free from the threats of various environmental pollutions. In China, health is one of the most fundamental and important conditions of urban livability (Zhang et al., 2006).

2.3.4. Safety category

Safety means that residents of a city or the residential areas of a city can enjoy their lives without feeling threatened, harmed or evicted from their households. If the residents cannot effectively protect their properties and personal safety from danger or disaster (no matter they are man-made or nature-induced), it would be unlikely for the city to be livable. We can evaluate urban safety from the occurrence of urban crimes, incidents of urban disasters and relevant events (Yu et al., 2014).

2.4. Method of Principal Component Analysis – based information rearrangement

Although using the indicator system could produce a relatively comprehensive image of urban livability, we also realize that individual indicators likely contain repetitive information when they are used to gauge urban livability. In addition, using one comprehensive index to measure urban livability often is more manageable and practical from a policy perspective than using a set of indicators (Beames et al., 2018; Newman, 1999; Wu, 1997). Our goal is hence to remove possible overlapping information among individual indicators by rearranging the data space and construct a comprehensive index from the existing indicators for urban livability measurement. A principal component analysis (PCA) method can achieve both purposes (Fu, 2013; Muriithi and Yu, 2015). PCA, also known as the spindle analysis, is to extract a small amount of representative key indicators via mathematical transformation under the premise of maintaining the main information of the sample. Evaluation of urban livability by means of PCA is to summarize and integrate a large number of likely correlated factors into a group of independent components that carry different amount of information of the original set of information. Detailed steps of applying PCA in this study follow closely what Reid et al. (2014) have described in their study. First, we will construct the original data matrix and make them dimensionless (by standardization) and all within the range of [0, 1]. Then we will calculate the eigenvalues and the orthonormal eigenvectors of the correlation coefficient matrix for the dimensionless data matrix. Finally, we will obtain the independent components and assign their corresponding eigenvalues’ contribution rates as the coefficients of the components in an additive model to generate the urban livability index. Since our purpose is to generate the urban livability index, all principal components will be retained. In this process, the data space becomes orthogonal while the information remains intact (Reid et al., 2014).

3. The indicator system

3.1. GIS and remote sensing generated indicators

Based on the four categories discussed above and the study by Zhang and colleagues (Zhang et al., 2006), there are many ways that we can generate effective livability measuring indicators. Oftentimes studies use data from readily compiled statistical yearbooks or field surveys. In the current study, however, we attempt an alternative way with GIS and remote sensing technology to build the indicators. Specifically, we compile 15 indicators for the four categories in Table 1 to be included in the system. We give brief descriptions of the indicators in each category below.

3.1.1. Convenience

Cities are residents’ cities. A livable city means its residents can live a convenient life. The convenience category includes indicators that describe the accessibility to daily public transportation facilities and the

Table 1
System of indicators.

Categories	Individual Indicators (with positivity and negativity towards livability)
Convenience	Distance to urban transit stations (negative)
	Density of urban transit lines (positive)
	Distance to urban center (negative)
	Distance to commercial facilities (negative)
	Distance to medical facilities (negative)
	Distance to recreation facilities (negative)
	Distance to elementary & secondary schools (negative)
Amenity	Vegetation coverage (positive)
	Distance to parks & squares (negative)
	Distance to universities & research institutes (negative)
Health	Distance to primary roads (positive)
	Distance to manufacturing facilities (positive)
	Distance to noisy open markets (positive)
Safety	Distance to road intersections (positive)
	Distance to toxic chemical facilities or gas stations (positive)

convenience of daily urban life. The accessibility to daily public transportation facilities includes the density of urban transit lines, the distances to urban transit stations and urban center. The convenience of urban daily life includes the distances to nearest commercial facilities, medical facilities, recreation facilities, elementary and secondary schools. Seven indicators are included in this category. They are calculated directly using the digital topographic map and ALOS remote sensing image with a grid cell resolution of 10 m.

3.1.2. Amenity

Indicators in this category include accessibility to natural environment and man-made facilities that make urban residents feel comfortable and pleasant. Amenity category includes aspects of the pleasant natural amenity and the satisfactory social amenity. The pleasant natural amenity refers to the beautiful natural landscapes including green spaces, parks, public squares and other open spaces. One the other hand, as one of the cities that promotes “invigorating China through science and education” strategy, the satisfactory social amenity of Changchun could be reflected in the accessibility to universities and research institutes. Three indicators are included in this category, namely, the vegetation coverage (VC), accessibility to nearest parks, and accessibility to nearest universities/research institutes. VC is calculated through normalized different vegetation index (NDVI) as follow:

$$\mathrm{VC}=\frac{\mathrm{NDVI}-\mathrm{NDVI}_{\mathrm{soil}}}{\mathrm{NDVI}_{\mathrm{veg}}-\mathrm{NDVI}_{\mathrm{soil}}} \tag{1}$$

Here $\mathrm{NDVI}_{\mathrm{soil}}$ and $\mathrm{NDVI}_{\mathrm{veg}}$ present the NDVIs of the unvegetated pixels and fully vegetative pixels, respectively. Accessibility to nearest parks or universities/research institutes are calculated as the distances of each cell to its nearest parks or universities/research institutes with a grid cell resolution of 10 m.

3.1.3. Health

The health category includes indicators that mitigate urban residents from health threats. This category considers the impacts of air pollution, noise pollution and other types of pollution. In Changchun, as in many other large and dense cities, air pollution is mainly caused by exhaust emission produced by cars and manufacturing facilities that are prone to produce dust and toxic gas. Noise pollution includes traffic noise pollution caused by vehicles through roads and life noise pollution generated by noisy open markets. Three indicators are included in this category, namely, the distances to the nearest primary roads, manufacturing facilities and noisy open markets. They are all generated through distance analysis in GIS using both the topographic maps and remote sensing image.

3.1.4. Safety

Indicators in the safety category are essential for urban livability in China (Yu et al., 2014; Zhang, 2007; Zhang et al., 2006). Safety category includes daily safety and potential safety. Daily safety includes traffic safety while potential safety relates to risks associated with natural and man-made disasters such as earthquakes, fires, hazardous materials leak and other relevant risks. Due to the sporadic characteristics of such events, we have a relatively difficult time to come up with indicators that have quality data. After researching through relevant studies (Dong and Yang, 2009; Dumbaugh, 2005; Gu et al., 2007; Li and Guo, 2006a; Yu et al., 2014; Zhang, 2007), and checking with available data, we settled for two indicators included in this category to represent daily safety and potential safety, respectively. Previous studies indicate that in Changchun, more than 50 percent of traffic accidents occurred at the intersections (Fu, 2013). We hence use distance to the nearest road intersections as the proxy of daily safety. As for potential safety, limited by data availability, we choose distances to the nearest toxic chemical facilities or gas stations to proxy urban potential safety. All distances are calculated via spatial analyst distance functions in ArcGIS®.

3.2. Data process with principle component analysis (PCA)

As aforementioned, prior to the PCA analysis, to remove the impacts brought due to data measuring units, and different ranges of the indicators, the evaluation first normalizes these individual indicators and makes them dimensionless and all within the range of [0, 1]. In addition, it is worth noting that the 15 individual indicators in Table 1 can be divided into positive indicators and negative indicators in terms of measuring urban livability. Positive indicators such as VC and distance to manufacturing facilities mean that the larger the index value, the better livability the area has. Negative indicators such as distance to urban center and distance to parks mean that the larger the index value (less convenient), the worse livable the area is (the positivity and negativity are identified in Table 1). To make the final calculated livability index generalizable across the board without losing the quantification power, we transformed negative indicators into positive indicators before normalization to ensure proper calculation and evaluation. Since most of the indicators are distance measures, to keep both positive and negative indicators within the same level of measurement, we multiply -1 to any of the negative indicators to make them “positive.”

After the PCA analysis, we retain all 15 principle components to keep all possible information since our task is not to reduce dimension (the result is identical if we only retain principle components that have eigenvalues larger than 1, in our case, the first three principle components). Their factor eigenvalues, cumulative contribution rates and loadings of each indicator are reported in Table 2 (note that all the indicators are now pointing to the same direction that larger the normalized indicator values, better livability). Following the practice in Reid et al. (2014), we use each principal component’s contribution rate (the percentage of variance of each principal component) as the coefficient of that principal component. To calculate a pixel’s urban livability index, we first replace the 15 original normalized indicators with the 15 principal components (using the loadings in Table 2), then we apply the coefficient to each principal component and sum them up to produce the urban livability index (*ULI*) for that pixel as in Eqs. (2)–(4):

$$PC_{ij}=\sum_{k=1}^{15} RS_{ik}\times Ld_{jk} \tag{2}$$

$$w_j=\frac{egv_j}{egv_{total}} \tag{3}$$

$$ULI_i=\sum_{j=1}^{15} PC_{ij}\times w_j \tag{4}$$

Here PC_{ij} is the jth principal component of the ith pixel. RS_{ik} is the normalized value (raw score) of the kth original indicator at the ith pixel. Ld_{jk} is the loading of the kth original indicator to the jth principal component (as in Table 2). w_j is the contribution rate of the jth principal component, which is calculated by dividing the eigenvalue of the jth principal component (egv_j) by the total eigenvalues of all the principal components (egv_{total}). ULI_i is the urban livability index of the ith pixel.

4. Results and discussion

4.1. Urban livability index of Changchun

Based on the Eqs. (2)–(4) and values from Table 2, we calculated the *ULIs* of 3,054,444 grid cells of the study area (Fig. 2). In addition, to evaluate the relative importance of each original indicator towards urban livability, we also calculated the weighted coefficient for each indicator as follows (5):

Table 2
Results of PCA.

	Principal Components				
	1	2	3	4	5
Eigenvalues	8.5473	1.6384	1.0386	0.7889	0.6929
% of variance	56.98	10.92	6.93	5.26	4.62
Cumulative %	56.98	67.90	74.83	80.09	84.71
	Loadings				
Distance to urban transit stations	−0.320	−0.171	0.071	0.166	−0.043
Density of urban transit lines	0.200	−0.364	−0.099	0.491	0.063
Distance to urban center	−0.180	0.026	−0.600	0.347	−0.528
Distance to commercial facilities	−0.284	0.198	0.113	0.071	−0.001
Distance to medical facilities	−0.317	0.027	0.009	−0.008	0.091
Distance to recreation facilities	−0.181	−0.528	0.231	0.232	0.266
Distance to elementary & secondary schools	−0.312	−0.090	−0.060	−0.063	0.070
Vegetation coverage	0.214	0.088	−0.113	0.431	0.377
Distance to parks & squares	−0.181	0.420	0.126	−0.012	−0.424
Distance to universities & research institutes	−0.170	0.199	−0.662	−0.185	0.440
Distance to primary roads	0.312	0.205	−0.018	−0.186	0.018
Distance to manufacturing facilities	0.261	0.370	−0.183	−0.013	−0.234
Distance to noisy open markets	0.319	−0.041	0.078	−0.006	−0.236
Distance to road intersections	0.285	0.071	−0.210	−0.362	0.032
Distance to toxic chemical facilities or gas stations	0.244	0.319	0.063	0.403	0.066
	Principal Components				
	6	7	8	9	10
Eigenvalues	0.5715	0.4936	0.3514	0.2164	0.1816
% of variance	3.81	3.29	2.34	1.44	1.21
Cumulative %	88.52	91.81	94.15	95.59	96.80
	Loading				
Distance to urban transit stations	−0.005	−0.014	0.151	0.128	0.027
Density of urban transit lines	0.108	0.634	−0.235	0.019	0.003
Distance to urban center	0.046	−0.239	−0.186	−0.201	0.173
Distance to commercial facilities	−0.086	−0.145	−0.637	0.146	−0.598
Distance to medical facilities	−0.003	0.000	0.155	0.291	0.165
Distance to recreation facilities	0.227	0.051	−0.210	−0.338	0.424
Distance to elementary & secondary schools	−0.067	−0.003	−0.214	0.547	0.346
Vegetation coverage	−0.731	−0.248	0.068	0.036	0.052
Distance to parks & squares	−0.428	0.587	0.172	0.053	−0.047
Distance to universities & research institutes	0.105	0.260	0.162	−0.004	−0.309
Distance to primary roads	−0.025	0.065	−0.217	−0.213	−0.027
Distance to manufacturing facilities	0.084	−0.148	0.231	0.239	0.014
Distance to noisy open markets	−0.025	−0.043	−0.082	0.208	−0.144
Distance to road intersections	−0.109	0.123	−0.433	0.245	0.390
Distance to toxic chemical facilities or gas stations	0.417	−0.029	0.111	0.458	−0.108
	Principal Components				
	11	12	13	14	15
Eigenvalues	0.1552	0.1320	0.0840	0.0725	0.0357
% of variance	1.04	0.88	0.56	0.48	0.24
Cumulative %	97.84	98.72	99.28	99.76	100
	Loading				
Distance to urban transit stations	0.132	−0.150	0.191	0.297	−0.793
Density of urban transit lines	0.209	0.180	−0.140	0.082	0.033
Distance to urban center	−0.169	0.019	0.028	−0.103	−0.009
Distance to commercial facilities	0.062	0.095	−0.072	0.177	0.024
Distance to medical facilities	−0.244	0.828	−0.073	−0.047	−0.034
Distance to recreation facilities	0.227	0.047	0.254	−0.017	0.015
Distance to elementary & secondary schools	0.282	−0.302	−0.193	−0.448	0.073
Vegetation coverage	−0.014	0.001	0.016	−0.009	−0.017
Distance to parks & squares	−0.126	−0.116	0.024	−0.039	0.038
Distance to universities & research institutes	0.074	−0.048	0.216	−0.098	−0.045
Distance to primary roads	−0.054	0.129	−0.414	−0.439	−0.586
Distance to manufacturing facilities	0.608	0.160	−0.272	0.312	0.016
Distance to noisy open markets	0.228	0.223	0.706	−0.396	−0.069
Distance to road intersections	−0.255	−0.017	0.197	0.447	−0.083
Distance to toxic chemical facilities or gas stations	−0.452	−0.220	−0.027	−0.060	−0.054

$$wc_k = \sum_{j}^{15} Ld_{jk} \times egv_j \tag{5}$$

Where wc_k is the weighted coefficient of the kth original indicator. Ld_{jk} is the loading (Table 2) of the kth original indicator to the jth principal component. And egv_j is the eigenvalue of the jth principal component. In addition, the mean values of all the normalized indicators across the 3,054,444 pixels are also reported in Table 3.

First, from Table 3, we can see that the individual indicators are contributing to the right directions towards urban livability. The positive sign indicates that higher the value of the individual indicator, better urban livability, while the negative sign indicates lower the value, better urban livability. Table 3 clearly depicts that in Changchun's urban core area, areas that are closer to schools, urban transit stations, urban center, medical facilities, commercial facilities, recreation facilities, universities and research institutes, parks and squares

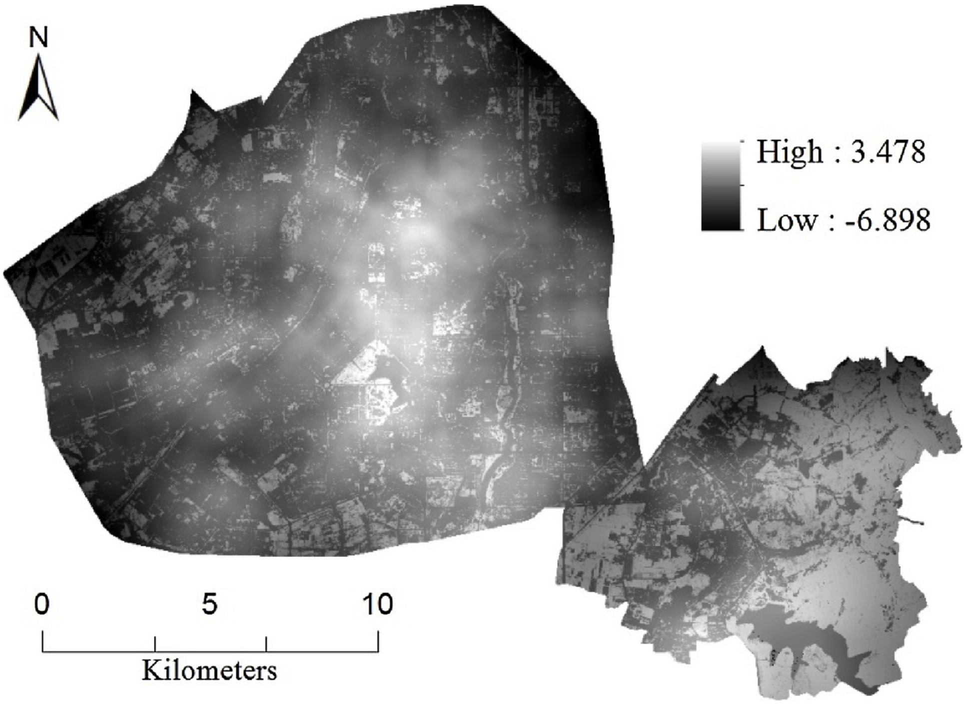

Fig. 2. ULIs of 3,054,444 grid cells in Changchun.

and other open spaces have higher livability. On the contrary, areas that are closer to potential risks, manufacturing facilities (potential industrial pollution), primary roads, noisy open markets and road intersections tends to have lower livability. Places with higher VC values also tend to have better livability. This pattern is also observable from Fig. 2 in which the urban center and the southeast part of Changchun's city proper tend to have higher livability due to their closeness to various schools, open spaces and distance from potential risks. Areas that are mainly close to major roads tend to have lower livability because of their relative proximity to roads, road intersections and manufacturing facilities. In addition, the magnitude of the weighted coefficients (which signifies the relevant importance of the individual indicators) also suggests that distance from potential risks and accessibility to elementary and secondary schools have higher importance regarding a specific place's livability, while vegetation cover, accessibility to parks and squares tends to be relatively less important (Table 3). The results make sense in China's urban scenarios and per our indicators' design. In today's Chinese cities, with ever-improving living standards, livability gears more towards being away from potential threats and convenient to primary and secondary educational institutes, places that are safer and close to schools are often regarded as more livable.

Second, by plotting the absolute values of the weighted coefficients of each individual indicator, and their mean values on a Quadrifid Graph, we can see the distribution of the average scores and their importance (Fig. 3). Following Jiang and Gao (2011)'s practice, we divide the 15 individual indicators to four categories and report them in Table 4. Indicators in category 1 suggest high value with high importance (both are above average). There are 4 individual indicators in category 1 and all of them are of convenience category in our livability assessment system, which suggests that the conditions of livable convenience (distances to various convenience facilities are reasonably short) in our study area are relatively good. As the capital city of Jilin Province and the central city in Northeast China, public transportation and daily life in Changchun is indeed rather convenient. Category 2's indicators are of higher importance but below average values. Five individual indicators are in this category including one safety, three health and one convenience indicators, which suggests the health and safety conditions in the city proper of Changchun is worth particular attention for improvement. With the ever-increasing urban land

Table 3
Coefficients and mean values of the 15 individual indicators of ULI.

Importance Rank	Individual Indicators	Weighted Coefficients	Mean values
1	Distance to toxic chemical facilities or gas stations	3.271	0.241
2	Distance to elementary & secondary schools	−2.849	0.803
3	Distance to urban transit stations	−2.754	0.890
4	Distance to manufacturing facilities	2.702	0.221
5	Distance to primary roads	2.660	0.100
6	Distance to noisy open markets	2.615	0.188
7	Distance to urban center	−2.407	0.458
8	Distance to medical facilities	−2.397	0.769
9	Distance to commercial facilities	−2.319	0.736
10	Distance to road intersections	2.042	0.130
11	Vegetation coverage	1.954	0.249
12	Density of urban transit lines	1.789	0.151
13	Distance to recreation facilities	−1.656	0.684
14	Distance to universities & research institutes	−1.453	0.759
15	Distance to parks & squares	−0.955	0.626

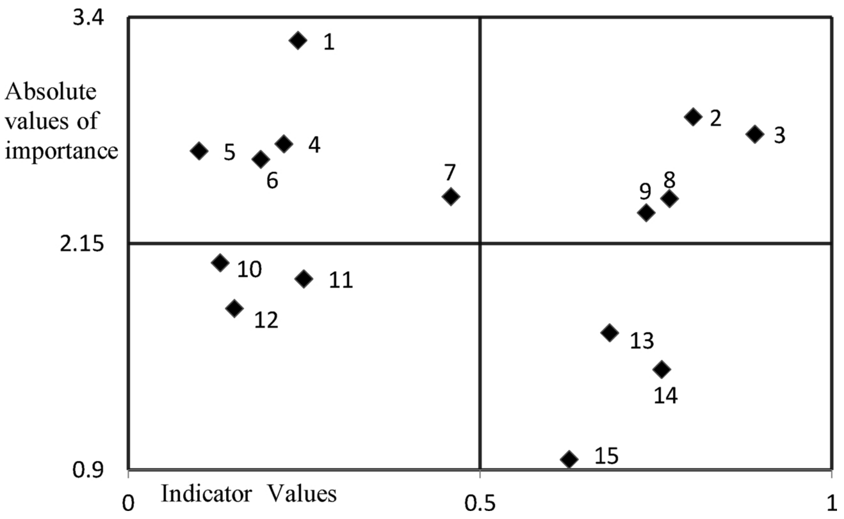

Fig. 3. Mean values and weighted importance of the 15 individual indicators.

expansion and urban population in China, the potential urban public safety concern is an important factor restricting the development of Chinese cities, and is currently facing serious challenges (Yu et al., 2014) that can affect livability of the city. Changchun is of no exception. Meanwhile, with the rapid economic development of Changchun, noise pollution, air pollution and other types of pollution also become more severe. As a traditional heavy industrial base and well-known "vehicle city" in China, numerous industrial enterprises and over one million vehicles bring tremendous pressure on air pollution treatment and haze control. Besides air pollution, noise pollution also affects Changchun's livability greatly because of outdated zoning codes, rapid growth of vehicle ownership, and overcrowded and severely inadequate parking facilities. In addition, as the city expanses rapidly in recent years, the convenience indicator represented by the distance to urban center follows a generally declining trend.

Indicators in category 3 and 4 are of less interests due to their relative under average importance. Both categories have 3 individual indicators in them. Specifically, comparing to the other livability indicators, traffic accidents, vegetation coverage and urban transit lines are of less importance but also requires some attention due to their below average values. On the other hand, access to recreation facilities, universities and research institutes, and open space seem to be of relatively lower importance but above average values than other livability factors. In summary, Fig. 3 and Table 4 suggest that in Changchun's urban livability scenario, health category needs immediate attention while convenience condition is rather adequate.

4.2. How livable is livable?

The discussions from Fig. 3 and Table 4 naturally lead to the next question: now we have an urban livability index for each pixel in Changchun. We also know how the original indicators contribute to such index and their individual importance and values. What are the standards that we can use to judge whether or not a specific *ULI* value can be regarded as livable? The *Livable City Scientific Evaluation Criteria* (*Criteria* henceforth) issued by the Ministry of Construction (PRC, Mo.E.Pot., 2007) has set up a series of standards regarding some of the original indicators that we can use to determine the answer to how livable is livable. To facilitate discussion, we introduce the concept of "benchmark livability" for any place. A place is said to be benchmark livable if it satisfies the minimum standards as defined in the *Criteria*. As the name suggests, the concept serves as a benchmark to gauge a place's livability and can also be used to calculate a benchmark *ULI* value.

Per the *Criteria*, a place is benchmark livable when its distance to commercial facilities is 1 km or less; to medical facilities is 1 km or less; to recreation facilities is 1 km or less; to elementary & secondary schools is 1 km or less; to parks and squares is 500 meters or less; to universities and research institutes is 1 km or less; and its vegetation coverage is over 35%. In addition, the Ministry of Housing and Urban-Rural Development devised Code for Design of Urban Road Traffic Facility (PRC, M.o.H.a.U.-R.D.o.t., 2011) suggests that a place is benchmark livable if it is less than 300 m from urban transit line, and if it is located within an area with 4 km/km^2 density of transit lines. For distance to urban centers, our study considers both the size of the city proper of Changchun and opinions from governmental officials. Local scholars and official documents suggest that places that are within 8810 m away from the urban center can be considered as benchmark livable (Fu, 2013). By consulting again quite a few governmental documents (PRC, M.o.C.o.t., 2002, 2007; PRC, Mo.E.Pot. et al., 2008, 2014; P.R.C., M.o.H.a.U.-R.D.o.t., 2005, 2011; P.R.C, M.o.H.o.t., 2010), the study determines that a place is benchmark livable if its distance to primary roads is more than 200 m; distance to manufacturing facilities is more than 500 m, distance to noisy open markets is more than 250 m; distance to road intersections is more than 350 m, distance to toxic

Table 4
Categories of 15 individual indicators.

Quadrant	Characteristic	Individual indicators included
I	Both the absolute values of importance and the means of normalized values of the individual indicators are comparatively high	Distance to elementary & secondary schools, Distance to urban transit stations, Distance to medical facilities, Distance to commercial facilities
II	The absolute values of importance are high while the means of normalized values are low	Distance to toxic chemical facilities or gas stations, Distance to manufacturing facilities, Distance to primary roads, Distance to noisy open markets, Distance to urban center
III	Both the absolute values of importance and the means of normalized values are comparatively low	Distance to road intersections, Vegetation coverage, Density of urban transit lines
IV	The absolute values of importance are low while the means of normalized values are high	Distance to recreation facilities, Distance to universities & research institutes, Distance to parks & squares

chemical facilities and gas stations is more than 250 m. Worth noting here is that these criteria are in no way fixed for any city's livability standards. They are more specific in Changchun's case, and shall be adjusted accordingly if the study area is elsewhere.

After transforming these benchmark livable values to normalized values (as the raw scores in Eq. (2)), we can calculate the *ULI* that represents the benchmark livability using Eqs. (2)–(4) as of being -1.672 in Changchun for the entire study area. Worth noting here is that the sign of the *ULI* is of less importance since the value zero for the *ULI* doesn't have a clearly defined meaning here. If anything, the benchmark livable *ULI* value, −1.672, serves as a true dividing point separating less livable from better livable places per our indicators design and *ULI* calculation. Yet again, the signs of the *ULI* value are by-products from the algebraic calculation. The calculated maximum of Changchun's *ULI* is 3.478 and the minimum is -6.898 among the 3054444 grid cells of the study area. *ULI*s of 1760968 grid cells which accounts for 57.63% of the total study area are more than the benchmark *ULI* of −1.672, suggesting that slightly over half of Changchun's city proper's livability is above or close to the benchmark values. While the other 42.37% are below par. According to the benchmark livable *ULI*, we divided the study area into 4 livable categories, namely, highly livable (*ULI* ranges from −0.224 to 3.478), livable (−1.672 to −0.224), less livable (−3.194 to −1.672) and not so livable (−6.898 to −3.194) (Fig. 4). The division of the categories is done in GIS based on the Natural Break (Jenks) approach by holding the second (from lowest to highest) division break value at −1.672 (the benchmark value, the original second division break value was −1.6895, very close to the benchmark value).

It can be seen from the livable distribution map (Fig. 4) that the highly livable areas are mainly in the center of the study area and Jingyue development district (the southeast part of the city proper). The center of the study area is a relatively developed region with a highly-developed road network, mature public facilities, and other life-convenient infrastructure such as schools, parks and open spaces. Being a predominantly residential area, this part of the city enjoys far less threats from adversary factors such as toxic chemical facilities and gas stations so that the residents there live a convenient life, and a pleasant environment far away from urban industrial zones. On the other hand, as Changchun's newly developed district, the Jingyue development district is another relatively highly livable area in our study area with superior natural environment and more mature community design. On the contrary, the edge of the study area is not so livable mainly due to its inconvenient transportation conditions, incomplete supporting facilities, far away from the urban center, and densely distributed industrial facilities.

The distribution of livability of Changchun is of a typical industrial city that has completed its industrial structure upgrading and starts to have clear stratification of different land use zones. After the economic reform in China in the late 1970s, but more importantly after the early 1990s' deepening of economic reform and State-Owned Enterprise reform, as one of the old manufacturing industrial centers, Changchun successfully seized the opportunity to transfer its inner-city industries to the outskirts of the city proper and encouraged more service-oriented industries in the inner city to provide its residents a more convenient and livable environment. By using a recent satellite image and a series of topographic maps, this investigation provides a rather robust quantitative analysis and interpretation of such process.

5. Conclusion

In the current study, for the first time we have calculated and assessed urban livability by applying GIS and remote sensing techniques and a PCA-based data synthetization approach. The GIS and remote sensing techniques are applied in many other land use and urban studies (Appiah et al., 2015; Buyantuyev and Wu, 2012; Clapham, 2003; Coulter and Stow, 2009; Dal'Asta et al., 2012; El Alfy, 2016; Fu, 2013; Guindon et al., 2004; Imhoff et al., 2010, 1997; Lu and Weng, 2005, 2006; Luo et al., 2008; Wu et al., 2015), but seldom used for livability investigation. The proposed PCA-based assessment system is able to derive an understandable and measurable *ULI* for urban livability study. Such strategy has been adopted elsewhere for its relative understandability and information retaining capability (Reid et al., 2014; Yu and Fang, 2017; Yu et al., 2014). According to the living environment concept of "convenience, amenity, health and safety" proposed by WHO and considering the rules of being "scientific, hierarchical, measurable and available", we selected 7 indicators in the convenience category, 3

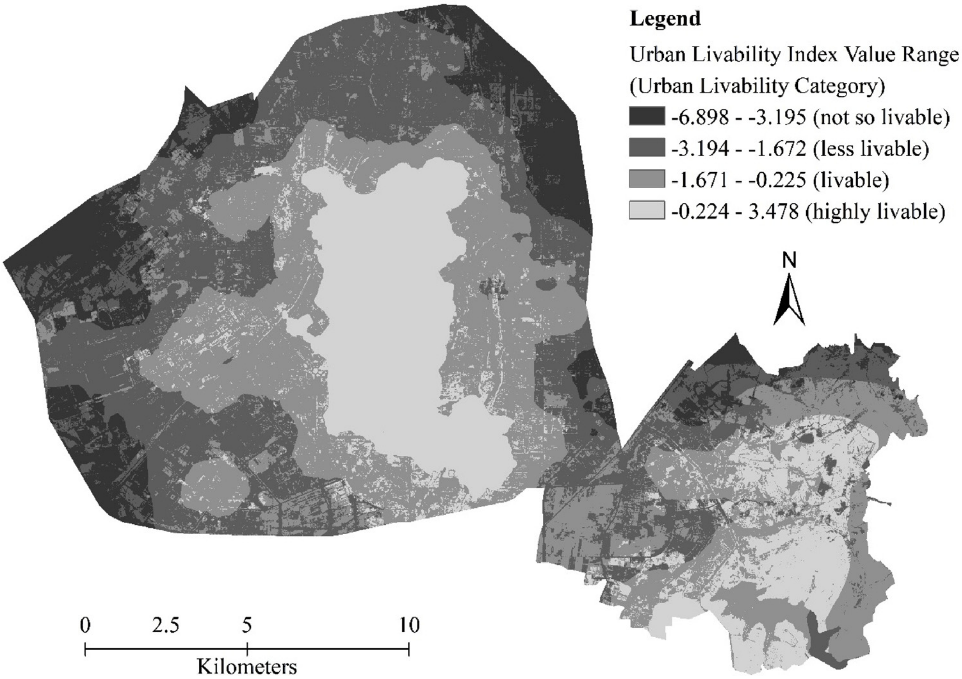

Fig. 4. Urban livability in Changchun.

indicators in the amenity category, 3 indicators in the health category and 2 indicators in the safety category to establish the assessment system. Information derived from 14 topographic maps at the scale of 1:10000 and a 2014 ALOS remote sensing imagery is used to produce the data for the 15 indicators. All the 15 individual indicators are extracted by GIS and RS with a grid resolution of 10 m. Using PCA-based method, we obtain 15 principal components and determined their contribution through their eigenvalues and the eigenvectors (loadings) of each principle component. We then constructed the Urban Livability Index (*ULI*) for each grid cell. Based on the derived *ULI* and the standard benchmark values of the individual indicators we compiled from various sources and investigations, we present the urban livability scenario in Changchun's city proper in 2014.

The proposed urban livability assessment system and the research method is conducive to enable the government to devise appropriate policies and take proper actions to improve any city's livability from a quantitative perspective. The results from the current study provide a timely addition to support sustainable urban land use policy-making under China's current new-type urbanization and ecological civilization initiatives. Urban residents' health and convenience are the two primary concerns when adjusting and implementing urban land use plans. The proposed approach is also effective to extract individual indicators from readily available and relatively accurate and objective data sources. Introduction of data sources from available topographic maps and satellite images to land use studies through GIS and remote sensing techniques might bring new research opportunities and insights. We can extend the urban livability assessment system to other cities and easily construct similar livability index for assessing their livability. Based on the current study, our next step is to enlarge the indicator system of urban livability (including natural environment data) and further improve the locational precision of indicator extraction. With the rapid development of urban construction, we could update the index data of the individual indicators and conduct dynamic analysis and comparison of Changchun's livability with more data and updated information. The current study provides an effective and efficient alternative to other urban livability ranking systems and livability assessment. With more in-depth future understanding of urban livability and urban residents' dynamic demands for a livable city, the proposed approaches in this study can easily adopt to such changes and assist urban planners, city officials and urban residents to generate a relatively objective image of urban livability of the places they call home.

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