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# Livability Assessment of Tianjin Sino-Singapore Eco-City Based on Multi-Source Data

**Dacheng Wang[1,a], Xiaojing Yao[1,*], Yuhui Fu[2,b]**

*[1]Aerospace Information Research Institute, Chinese Academy of Sciences, Beijing, China*
*[2]Department of Architecture and Art, Zhejiang University of Technology, Hangzhou, Zhejiang, China*
*[a]wangdc@aircas.ac.cn, [b]13819127269@163.com*
*Corresponding author: yaoxj@aircas.ac.cn*
*These authors contributed equally to this work.*

***Abstract:*** *Evaluating the comfort level of residents' lifestyles quantitatively and addressing living issues are the key to realizing a better regional life. Taking Tianjin Sino-Singapore eco-city as the study area, this paper establishes a livability evaluation framework consisting of 26 secondary index systems by using the technique for order preference by similarity to an ideal solution model. This paper identifies the livability evaluation framework and builds the TOPSIS model according to multi-source data including remote sensing images, basic geographic information, government operations, controlling detailed planning data, and point of interest data. As a result, this paper analyzes different data outcomes and thus concludes the livability evaluation spatial distribution of Tianjin Sino-Singapore Eco-city.*

***Keywords:*** *livability assessment; Tianjin Sino-Singapore eco-city; TOPSIS model; evaluation system; spatial distribution*

## 1. Introduction

With the continuous progress of different aspects of society, China's urbanization has reached an unprecedented scale, and as a result, the overall assessment of urban livability has become more dominant. In the "Several Opinions on Further Strengthening the Management of Urban Planning and Construction" issued by the Central Committee of the Communist Party of China and the State Council, it is proposed that the previous urban development model is unsustainable. Therefore, an objective evaluation system of urban livability under the support of multi-source data to improve livability is in urgent need.

The study of urban livability began in the 1960s with Jane Jacobs' the Life and Death of Great American Cities, in which he first questioned and explored the livability of cities and called for the creation of cities more suitable for human habitation[1]. After 30 years of exploration, by the 1990s, the rapid economic development and expanding human needs had caused great damage to the ecological environment, and the human habitat was facing serious challenges. At this time, people began to reflect on the necessity and importance of the topic of urban livability. In China, the theory of livable cities was introduced by Professor Wu Liangyong, a member of the two academies, and other scholars whose book "*Introduction to the Science of Habitat*" systematically introduced the emergence, development, and main theoretical approaches to the science of habitat*[2]*. After that, there are more and more studies on livability. Some scholars on the connotation of the habitat environment, evaluation methods for theoretical discussion, the establishment of the habitat environment evaluation index system, and specific cities as an example, to explore the mechanism of change in the habitat environment. Other scholars have also studied the theory and method of habitat environment evaluation, respectively, and have done empirical analysis work with Hangzhou, Nanjing, and Beijing as examples.

At present, many scholars at home and abroad have conducted quantitative studies on urban livability, with many different evaluation scales. For example, at the city scale, Reiner et al. used various evaluation systems and frameworks, proposed a city dependency model, and explored the role and influence of infrastructure in livable cities*[3]*; Lei Linjie et al. constructed an evaluation system for urban livability in Hebei Province and used principal component analysis to evaluate the livability of 11 cities in Hebei Province*[4]*. 11 cities in Hebei Province by constructing a livability evaluation system and using principal component analysis to evaluate and analyze livability, and select evaluation indexes that have a significant impact on urban livability based on the analysis results. At the regional scale, Hao Xinhua et al. constructed a large-scale, fine-scale quantitative evaluation, and used the emerging streetscape

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pictures to evaluate street greening as a new walkability evaluation index*[5]*. At the individual community scale, Yuan Zhang et al. used TOPSIS method to construct an urban livability assessment model for Haidian District, and used MCS and Sobol methods to analyze the results for uncertainty and sensitivity*[6]*; Li Dawei et al. used GIS technology to construct a 500m×500m raster as the basic unit based on traffic vector data, point-of-interest data, remote sensing images, and other multi-source data*[7]*. The livability evaluation model was constructed by using the comprehensive index method.

However, most of the current research on urban livability belongs to the category of large-scale analysis, and there are relatively few discussions on the urban micro-scale. There are differences in the internal development and living environment of the same area of the city.. Based on the small-scale livability analysis of urban residential plots and other small-scale livability analyses, the problems existing in urban planning and development can be described at the micro-scale. At the same time, by observing the long-term, the monitoring results of the time series can more intuitively reflect the staged development process of a city, which is convenient for targeted adjustment and reform.

According to the above problems, based on the timeliness and spatial resolution of multi-source data such as remote sensing images and basic geographic information, this paper establishes a new livability evaluation framework consisting of 26 secondary indicators and five dimensions such as environmental health, traffic accessibility, urban safety, facility convenience, and economic prosperity.The counting of the number of facilities and the calculation of distances within the other ranges are realized by spatial statistics and spatial proximity analysis; spatial statistics are realized by counting the number of points of interest within a 500-meter buffer in each block, while spatial proximity analysis is realized by using the method of calculating the distance from the center point of each block to each point of interest..

## 2. Research area and research method

### *2.1. Overview of the study area*

The Sino-Singapore Tianjin Eco-City is a strategic cooperation project between the governments of China and Singapore. It is also the first eco-city developed and constructed in cooperation between countries. It is located in Tianjin Binhai New Area (40 kilometers away from the center of Tianjin), covering an area of 150 square kilometers. It is adjacent to Binhai New Area Central Avenue in the east, Ji Canal in the west, Ji Canal in the south, and Jinhan Expressway in the north, with convenient transportation and energy, the supply guarantee conditions are good; the construction of the eco-city shows the determination of the Chinese and New Zealand governments to deal with global climate change, strengthen environmental protection, save resources and energy, and provide positive discussions and models for the construction of a resource-saving and environment-friendly society. The demonstration requires the eco-city to strive to become a livable urban area with production development, affluent life, and good ecology, and provides a demonstration for exploring new urbanization paths with Chinese characteristics.

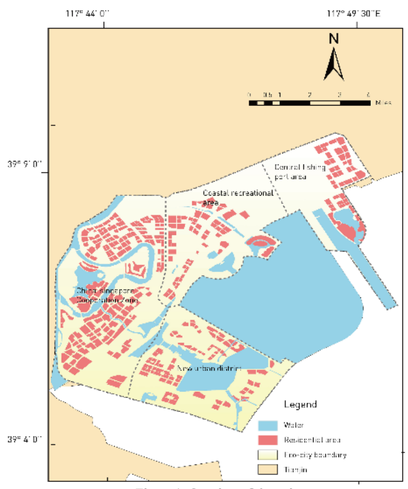

Figure 1: Oveview of th study area

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This study takes 373 planned residential plots in the eco-city as the research unit and divides the

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interior of the eco-city into 4 areas (see Figure 1) to study the livability of the eco-city.

### *2.2. The livability assessment process*

The livability evaluation process should include the selection of indicators and evaluation methods. According to the development trend and current situation of the eco-city, the livability evaluation is carried out in five dimensions using the TOPSIS model combined with the weighted average of indicators calculated by the entropy method. (Figure 2).

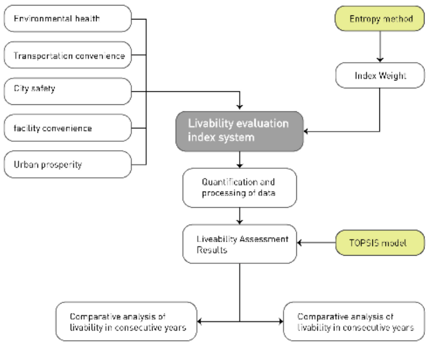


Figure 2: Livability assessment process

*Figure 2: Livability assessment process*

Whether a city is livable depends largely on the city's environmental comfort: living in a residential area with a higher urban greening rate and a lower noise index tends to be more comfortable. The selection of urban livability evaluation indicators and the construction of an evaluation system are the keys to accurately analyzing and judging the development level of a city. The content of livability includes people, nature, society, and resources. It is a complex system. Therefore, the constructed index system should be able to reflect the real natural environment, economic development, traffic conditions, infrastructure, and other conditions of a city; Long Ying et al, the method of redefining the livability index system of the urban system based on the new data environment; Zhang Wenzhong et al believe that whether a city meets the standard of "livable city" depends on the benchmark city of reference, and at the same time, the development of the city itself must be considered. Based on the above index construction principles and existing research results, the eco-city livability evaluation index system constructed in this paper combines remote sensing, planning, roads, points of interest, and other multi-source data, and refines five first-level indicators and 26 A secondary indicators:

The research data mainly includes urban planning and road network data, point of interest data, and remote sensing image data. The scope of urban planning data includes each residential area in the 4 districts of the eco-city. The research in this paper evaluates and analyzes the livability of the eco-city based on the scale of residential parcels. Map point of interest (POI) data generally refers to all geographic objects that can be abstracted as points, which are recorded as a certain coordinate in electronic maps and GIS tools. The research uses GIS tools to analyze each point of interest and obtain various attributes and spatial distribution.

In the calculation of various indicators, the green space coverage rate and the urban heat island index are obtained by inversion of remote sensing images. The green space coverage rate adopts the pixel binary model, and the calculation formula is as follows:

$$\mathrm{f_c} = (R - R_{\mathrm{soil}}) / (R_{\mathrm{veg}} - R_{\mathrm{soil}}) \tag{1}$$

Among them, R represents the reflectivity of the pixel, and $R_{soil}$ represents the non-vegetation part of the reflectivity of the pixel, and $R_{veg}$ represents the pure vegetation part. The urban heat island index is calculated by inverting the surface temperature after performing radiometric calibration and atmospheric correction on the Landsat 8 image.

Because traffic roads have a greater impact on noise in residential areas, in general, the distance between residential areas and traffic roads is positively correlated with noise pollution. The noise index is measured by calculating the distance between the center of the residential area and the traffic road; the impact degree of the disaster site takes the 500 m buffer zone of the disaster site as its impact boundary, and the distance from the residential area to the disaster site is calculated as the impact level. The greater

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the distance, the smaller the impact, and the residential area outside the buffer zone will not be affected. The counting of the number of facilities and the calculation of distances within the other ranges are realized by spatial statistics and spatial proximity analysis; spatial statistics are realized by counting the number of points of interest within a 500-meter buffer in each block, while spatial proximity analysis is realized by using the method of calculating the distance from the center point of each block to each point of interest.

*Table 1: Indicator selection and quantitative description*

| First-level indicator | Secondary indicators | Type of data | Quantitative method |
|---|---|---|---|
| Environmental health | The closest distance to the body of water | Controlling detailed planning data | Spatial proximity analysis |
| | Urban heat island index | Remote sensing data (landsat 7) | The remote sensing inversion method |
| | Green space coverage | Remote sensing data (landsat 8) | The remote sensing inversion method |
| | The closest distance to the pollution source | Pollution source data | Spatial proximity analysis |
| | The density of garbage spots | Junk point data | Spatial statistics |
| | Noise figure | Noise source data | Spatial proximity analysis |
| Transportation convenience | Traffic stop density | Bus stop data | Spatial statistics |
| | Road network density | Road network data | Spatial statistics |
| | Accessibility to transportation stations | Bus stop data | Spatial proximity analysis |
| Facility convenience | The density of cultural and educational facilities | Point of interest (POI) data | Spatial statistics |
| | Health care facility density | | |
| | The density of leisure and shopping facilities | | |
| | Food service facility density | | |
| | Financial services facility density | | |
| | The closest distance to cultural and educational facilities | Point of interest (POI) data | Spatial proximity analysis |
| | The closest distance to the healthcare facility | | |
| | The closest distance to leisure and shopping facilities | | |
| | The closest distance to a food service facility | | |
| | The closest distance to Financial services facilities | Point of Interest (POI) data | Spatial proximity analysis |
| City safety | Electronic monitoring of density | Electronic monitoring data | Space statistics |
| | Coverage density of emergency facilities | Emergency facility data points | Spatial proximity analysis |
| | Distance to emergency shelter | Emergency facility data points | |
| | The closest distance to the source of danger | Hazardous source data | |
| Economic prosperity | Diversity | Commercial facility's points of interest (POI) data | Simpson index analysis |
| | Aggregation | | Space statistics |
| | Distance to the business center | Business district data | Spatial proximity analysis |

*Table 2: Data usage and its quantification*

| Data type detailed data usage | Detailed data |
|---|---|
| Controlling detailed planning data | Residential land, Body of water |
| Basic geographic information data | Road network data, disaster point data |
| Point of interest (POI) data | Urban infrastructure, emergency shelters |
| Remote sensing image | Landsat 8 OLI image |

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### *2.3. Calculation of Indicator Weights*

#### *2.3.1. Entropy Method to Realize Weight Calculation*

The entropy method is a mathematical method used to judge the degree of dispersion of an indicator. The degree of dispersion of each index can be calculated by the entropy method and combined with the time dimension to determine the uncertainty of each index; the greater the degree of dispersion of the index, the greater the weight will be in the evaluation system. The specific implementation steps of the entropy method:

Assuming that the data has n rows of records and m variables, the data can be represented by an n*m matrix A (n rows and m columns, that is, the number of records in n rows and m feature columns)

Standardize the indicators, as follows:

Positive indicators: $I_{(i)} = (X_{(i)} - X_{(MIN)}) / (X_{(MAX)} - X_{(MIN)})$

Negative indicators: $I_{(i)} = (X_{MAX} - X_{(i)}) / (X_{MAX} - X_{MIN})$

(3) Calculate the proportion of the i-th record under the j-th indicator

(4) Calculate the entropy value of the jth index:

$$e_j = -k * \sum_{1}^{n} P_{ij} * \log (P_{ij}), \quad k = 1/\ln (n) \qquad (2)$$

(5) Calculate the difference coefficient of the jth indicator and obtain the weight of the jth indicator:

$$g_j = 1 - e_j \qquad (3)$$

$$W_j = \frac{g_j}{\sum_{1}^{m} g_j} \qquad (4)$$

Calculate the weight of each indicator by the entropy method:

*Table 3: Entropy method weight*

| Indicators | Index Weight |
|---|---|
| The closest distance to the body of water | 0.0061 |
| Urban heat island index | 0.0045 |
| Green space coverage | 0.0030 |
| The closest distance to the pollution source | 0.0139 |
| The density of garbage spots | 0.0784 |
| Noise figure | 0.0021 |
| Accessibility to transportation stations | 0.0007 |
| Traffic stop density | 0.0578 |
| Road network density | 0.0110 |
| Accessibility to the business center | 0.0485 |
| Diversity | 0.0888 |
| Aggregation | 0.0020 |
| The closest distance to the source of danger | 0.0153 |
| Accessibility to emergency shelters | 0.0016 |
| Electronic monitoring of density | 0.0420 |
| Emergency facility coverage | 0.0576 |
| Food service facility density | 0.1001 |
| The closest distance to a food service facility | 0.0013 |
| Financial services facility density | 0.1421 |
| The closest distance to financial services facilities | 0.0037 |
| The density of cultural and educational facilities | 0.0784 |
| The closest distance to cultural and educational facilities | 0.0022 |
| Health care facility density | 0.1233 |
| The closest distance to the healthcare facility | 0.0037 |
| The density of leisure and shopping facilities | 0.1101 |
| The closest distance to leisure and shopping facilities | 0.0017 |

#### *2.3.2. Technique for Order Preference by Similarity to an Ideal Solution Model*

The basic principle of the TOPSIS method is to sort by detecting the distance between the evaluation

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object and the optimal solution and the worst solution. If the evaluation object is closest to the optimal solution and farthest from the worst solution, it is the best; otherwise, it is the worst. Among them, each index value of the optimal solution reaches the optimal value of each evaluation index. Each index value of the worst solution reaches the worst value of each evaluation index.

1) Construct the normalized initial matrix

Assuming that there are n objects to be evaluated, and each object has m indicators, the original data matrix is constructed as:

$$X = \begin{matrix} x_{11} & \cdots & x_{1m} \\ \vdots & \ddots & \vdots \\ x_{n1} & \cdots & x_{nm} \end{matrix} \tag{5}$$

Construct a weighted norm matrix, and the attributes are vector normalized, that is, each column element is at the norm of the current column vector (using the cosine distance metric)

$$Z_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{n} X_{ij}^2}} \tag{6}$$

Standard matrix after normalization:

$$Z = \begin{matrix} Z_{11} & \cdots & Z_{1m} \\ \vdots & \ddots & \vdots \\ Z_{n1} & \cdots & Z_{nm} \end{matrix} \tag{7}$$

2) Determine the optimal solution and the worst solution

The optimal solution $z_j^+$ consists of the maximum value of each column element in Z:

$$Z_j^+ = (\max\{z_{11}, z_{21}, \cdots z_{n1}\}, \max\{z_{12}, z_{22}, \cdots z_{n2}\}, \cdots \max\{z_{1m}, z_{2m}, \cdots z_{nm}\}) = (Z_1^+, Z_2^+, \cdots, Z_m^+)$$

The worst solution $z_j^+$ consists of the minimum value of each column element in Z.

3) Calculate the closeness of each evaluation object to the optimal plan and the worst plan:

$$D_i^+ = \sqrt{\sum_{i=1}^{m} w_j (Z_j^+ - Z_{ij})^2}, D_i^- = \sqrt{\sum_{i=1}^{m} w_j (Z_j^- - Z_{ij})^2} \tag{8}$$

Where $w_j$ is the weight of the jth attribute, and the index weight is determined according to the entropy method.

4) Calculate the closeness of each evaluation object to the optimal solution

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-} \tag{9}$$

When $0 \le C_i \le 1$, $C_i \to 1$, it indicates that the evaluation object is better

Sort according to the size of $C_i$ and give the evaluation results.

According to the weights calculated by the index system and the entropy method, the TOPSIS method was used to obtain the livability assessment results of each block of the eco-city.

## 3. Results Analysis

### *3.1. Results Analysis: Environmental Health Assessment*

Environmental health is one of the key points in the construction of a livable city and is the most basic guarantee for residents' lives. Six indicators, namely green area coverage, urban heat island index, garbage site distribution density, nearest distance to water bodies, nearest distance to pollution sources, and noise index, can reflect the environmental healthiness of the Eco-city objectively. Based on the weights calculated by the entropy method, the environmental health indicators at the scale of residential plots are influenced by the green area coverage, the distribution of garbage sites, and the distribution of

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pollution sources; among them, the distribution density of garbage sites plays a more important role in the overall study of livability. In addition, In the Tianjin Sino-Singapore Eco-city, the central port fishing area has the best environmental health, followed by the coastal recreational area, Sino-Singapore cooperation zone, and new urban district, where good environmental health areas are scattered.

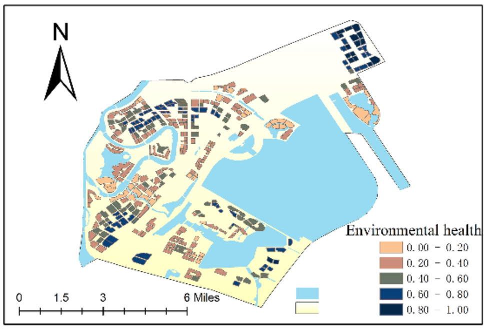

Figure 3: Environmetal health assessment

*Figure 3: Environmental health assessment*

### *3.2. Results Analysis: Traffic Convenience Assessment*

Convenient and smooth transportation networks are one of the important conditions for building a livable city, and all kinds of living activities of city residents depend on various transportation modes in the city. The three indicators of traffic station density, road network density, and traffic station accessibility can reflect the convenience of traffic in the Eco-city in a more objective way. Based on the weighting calculated by the entropy method, the traffic convenience indexes at the residential plot scale are more influenced by the density of traffic stations. In comparison, traffic accessibility and road network density have less influence on the evaluation of traffic convenience than traffic density. Moreover, in terms of spatial distribution, the Sino-Singapore cooperation zone has the best traffic convenience, while new urban districts and coastal recreational areas have weaker traffic convenience, and the central fishing port area has the worst traffic convenience. Among the Sino-Singapore cooperation zone, new urban district, and coastal recreational area, traffic convenience distribution is obviously uneven.

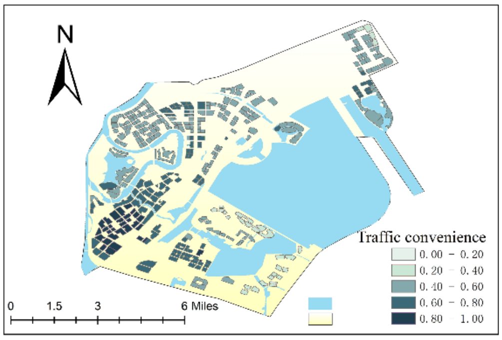

Figure 4: Traffic convenience assessment

*Figure 4: Traffic convenience assessment*

### *3.3. Results Analysis: Urban Safety Assessment*

The safety of the city is closely related to the personal interests of the residents, and the safety and security of the city are also important conditions for building a livable city. The three indicators of electronic monitoring density, distribution and accessibility of emergency shelters, and nearest distance of danger sources can reflect the convenience of transportation in the Eco-city more objectively. Starting from the weights calculated by the entropy method, the urban safety indexes at the scale of residential plots are more influenced by the density of emergency facility coverage and less influenced by the distance of emergency shelter places. The density of electronic surveillance in the south of the Sino-Singapore Cooperation Zone and Linhai New Town is high, and the distribution of emergency shelters is dense, but there are more dangerous sources in the city, and the city's safety is lower. The overall safety index of the city shows the characteristics of "down to the center and up to the edge, down to the south

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and up to the north".

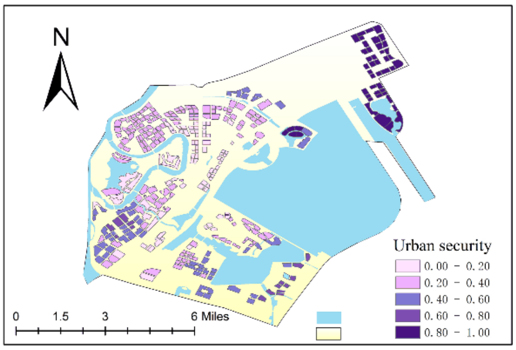


Figure 5: Urban security assessment

*Figure 5: Urban sccurity assessment*

### *3.4. Results Analysis: Facility Convenience Assessment*

The construction of schools, hospitals, shopping, and dining facilities, and financial facilities should not only meet diverse needs but also improve accessibility to related facilities. The construction of urban infrastructure within the Eco-city is concentrated in the central city, and shows a gradual decline in the surrounding area, with large differences in the convenience of facilities between cities. In terms of categories, the influence of different facilities on the convenience evaluation index from high to low as follows: density of financial service facilities, the density of medical and health facilities, the density of leisure and shopping facilities, the density of food service facilities, and density of cultural and educational facilities. And, these elemental indicators play a vital role in the overall study for the livability evaluation. Moreover, in terms of spatial distribution, the southern part of the Sino-Singapore cooperation zone has the best facilities. Among the rest areas, the facility convenience is relatively low, and the central fishing port area has the lowest facility convenience.

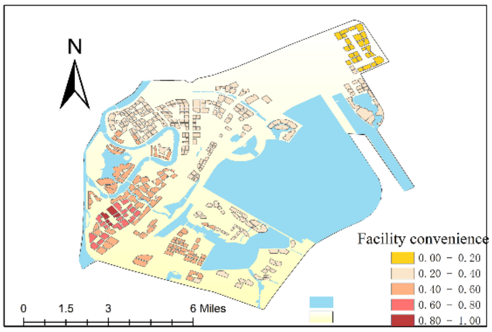


Figure 6: Facility convenienc assessment

*Figure 6: Facility convenience assessment*

### *3.5. Results Analysis: Economic Prosperity Assessment*

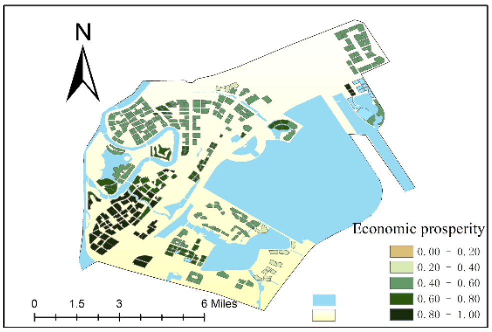


Figure 7: Economic prosperity assessment

*Figure 7: Economic prosperity assessment*

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An important indicator of urban development is economic prosperity, and the improvement of the economic level and efficiency of the city is important for creating a livable city. The three indicators of diversity, agglomeration, and distance to commercial centers can reflect the economic prosperity of the Eco-city more objectively. From the weights calculated by the entropy method, the economic prosperity indicators at the residential plot scale are more influenced by diversity and less influenced by aggregation. The economic prosperity of the Eco-city is highest in the center of the city and decreases in the surrounding areas; the economic prosperity of the southern region is higher than that of the northern region.

## 4. Conclusions

This study takes the residential parcels in the planning data of the Eco-city as the research unit and uses multi-source data such as high-resolution remote sensing images, point-of-interest (POI) data, and land data to construct a livability evaluation index system through the entropy value method and TOPSIS model to evaluate the whole Sino-Singapore Eco-city in terms of zoning and sub-indexes. This study shows that facility accessibility indicators are the most important indicators of livability in Tianjin Sino-Singapore Eco-city. Meanwhile, environmental health indicators account for the smallest proportion of the livability evaluation of Tianjin Sino-Singapore Eco-city. In terms of spatial distribution, the various indicators have their own single distribution scheme based on their influence indicators and should be considered individually.

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