A Study on Ecological Redline Delineation of Land Areas in Shenzhen

Xu Yali1,2,3, Li Jiacheng1, Hong Wuyang2, Chen Xiaoxiang1, Yue Jun1, Zhang Xi1, and Luo Tingwen3

1 Urban Planning &Design Institute of Shenzhen, Guangdong, 518031
2 Shenzhen Urban Planning & Land Resource Research Center, Shenzhen, Guangdong, 518034
3 Key Laboratory of Urban Land Resources Monitoring and Simulation of the Ministry of Land and Resources, Shenzhen, Guangdong, 518034

49641238@qq.com, 13751174721

Abstract. In the context of reform in the mechanism of ecological civilization in China, delineation and management of ecological redlines is of great significance to maintaining the ecological security of the cities. The geographical focus of this study is Shenzhen – a city with obvious disparity between the state of development and level of ecological protection as well as a strong demand for ecological products. Considering having an accurate boundary of ecological redline, building an operability management system, and shaping measures for implementation and operation, this study uses ArcGIS, a tool of spatial analysis, to study the indicators, methods, and technical processes of ecological redline delineation on the city and county levels. It adopts an integrated assessment approach encompassing multiple ecological indicators and key technologies to explore the scope of ecological redline delineation. The results of this study are as follows: (1) Land delineated within the scope of ecological redline management is spread over a total of 557.47 km², accounting for 28.53% of the city area, which mainly features low mountains and hills covered with vegetation in southeastern and central Shenzhen. It effectively connects with the ecological control line. (2) Some important ecological areas are not covered within this ecological redline delineation due to relatively scattered distribution. However, these areas are a part of the system comprising a pattern of urban ecological security, ecological redline, ecological land outside the delineated redline, and greenbelts within the construction lands. (3) Within the delineated ecological redline, a total area of 9.25 km² is still allocated as construction land, mainly for linear engineering and civic facilities. Therefore, planning is required for re-greening and ecologically transforming these areas for the sake of maintaining the ecosystem.

1. Introduction
The rapid pace of urbanization represented by a disorderly expansion of construction land in China is proving to be highly detrimental to ecology. In this context, China has called for establishing a complete system of ecological civilization and delineating ecological protection redlines. Studies on ecological redlines by scholars have focused on the structure of the ecological redline system[1], definitions and categories[2], delineation methods and case studies[3], management systems[4], supervision and evaluation[5]. All these studies have deemed ecological redline delineation as the basis.
Studies on ecological redlines vary in terms of scale and region, while indicators are different for different regions as well. Chinese scholars have undertaken studies on ecological redline delineation using different scales and levels of regions, such as province, region, city, district, county, town, ocean, and island. Ecological redline delineation works on the city and county levels have much higher requirements for accuracy and prevision as they directly provide the legal basis for spatial planning and management.

Moreover, technical method of redline delineation needs to be studied from the perspective of scale and layout. For the scale, models[6] of ecological carrying capacity and ecological footprint are the major means for assessing the threshold value of minimum ecological land area. This method is mainly suitable for regions where constructions are expanding. For spatial layout, there are four main methods: (1) Delineation after Superimposition and Integration of Classified and Graded Natural Ecological Elements: For instance, Li B, et al. [7] delineated redline after the training of gradient, elevation, distance with water area, ecological sensitivity and other elements based on the Bayesian Network. (2) Redline Delineation Based on Ecological Functions and Ecological Sensitivity: This method is about establishing an indicator system of ecological protection significance and sensitivity as well as an assessment model for each indicator, integrating and superimposing individual assessment results to obtain redline scope[8-9]. For instance, Guidelines for the Ecological Protection Redline released by the state in 2017. (3) Redline Delineation Based on Superimposition and Integration of Individual Functions of Natural Resources: For instance, Ye JT[10] obtained the scope of ecological redline through five individual function redlines, namely comprehensive forest resources, water resources, cultivated land resources, human and historical resources, and landscape aesthetics. (4) Ecological Redline Delineation Based on Analysis of Ecological Network Pattern: For instance, WangYC[11] built ecological network jointly constituted by subjective space and constitutive space based on ecological network planning method, and delineated ecological redline of Nanyi Lake Region in Xuancheng, Anhui. By comparison, the first method delineates ecological redline by simple superimposition of elements, which has strong operability, but lacks standards for determining and demarcating element indicators and ignores connection between each element. Meanwhile, the second method gives consideration to elements of land utilization and surface vegetation coverage, lays emphasis on functional protection of ecosystem, meets the requirements of regulation of national land space, but lacks comprehensive consideration of integrity and connectivity of ecosystem. As for the third method, it superimposes and integrates redline of various natural resources, but lacks comprehensive consideration to multiple ecological service functions of ecosystem. Lastly, the fourth method considers the integrity of regional ecosystem, but needs to further identify key ecological elements. As observed above, ecological redline delineation methods are diversified and have their respective advantages and disadvantages. Thus, it is necessary to select the appropriate ecological redline delineation method according to research scale, research subject, data acquisition, accuracy requirements, and circumstances.

In conclusion, the delineation of ecological redline should give full consideration to multiple service functions of the ecosystem. It should analyze the relationship between ecological resources and human activity, comprehensively coordinate protection and utilization of natural ecological resources including “mountain, water, forest, farmland, lake, and grassland”, and build a complete, balanced, and sustainable ecosystem. Furthermore, the delineation of ecological redline on the city and county levels should be enforceable and operable. Thus, there are special requirements for delineation method, process, accuracy, and coordination with relevant planning and management mechanism. In this regard, this study takes Shenzhen as an example to delineate ecological redline on the scale of city and country, and explores the method, process, and thinking approach for ecological redline delineation in high urbanization areas.
2. Area Profile and Data Source

2.1. Area Profile

Shenzhen is a coastal city in southern China, situated south of the Tropic of Cancer. It is surrounded by the eastern longitude of 113°46' to 114°37' and northern latitude of 22°24' to 22°52'. Spread over a total area of 1,954km², the city has nine administrative districts and one new district. It is a littoral area with low mountains and hills. The area terrain is high in the southeast and low in the northwest. Its main landforms include low mountains, gentle tableland, and terrace hills. This study takes the scope of the city as the study subject and ecological control line as the key area to carry out ecological assessment and explore ecological redline delineation.

2.2. Data Source

This study uses the following major data sources: Geographical Condition Census, Landsat8 remote-sensing images from summer of 2014, QuickBird high resolution images from July 2014, 2014 Land Use Change Survey, data from special investigation into the basic ecological control line, and data on species and ecological corridor in biological species conservation planning and early warning system of Shenzhen. Auxiliary data includes monthly rainfall data, soil, DEM, Overall Plan for Land Utilization, Division of Drinking Water Source Conservation Area, natural reserves planning, scenic area planning, and geological park planning.

3. Assessment Indicators and Methods

3.1. Technical Route of Assessment

In order to ensure the scientificity of ecological redline delineation, it is necessary to consider the relevance of regional ecological land, regional ecological processes, and ecological functions, and build a system of ecological security pattern characterized by “point-plane-network”. In this way, we can determine the ecological bottom line, in addition to optimizing and re-organizing land layout of ecological corridor, polygon and matrix. Therefore, on the basis of considering point and plane elements, namely significance and sensitivity indicators of ecological protection, this study introduces the network element, namely ecological network pattern indicator. Furthermore, as a high urbanization area, Shenzhen is characterized by a strong property right awareness among its locals, high demand for urban development, complex land utilization status, and lack of corresponding planning and policy management. Therefore, ecological redline delineation is linked with enforceability and operability of the redline. Technical route diagram is shown in figure 1.

![Diagram of Technical Route of Assessment and Indicator System for Ecological Redline Delineation of Shenzhen](image)
3.2. Indicators and Methods
In line with the classification of urban land ecosystem, this study classifies urban land per different types of ecosystem: forest, mangrove forest (wetland), economic forest, water body, farmland, grassland, and settlements. Different ecosystems are rasterized, and rasterized cell is taken as the basic unit (30m*30m) of spatial quantitative assessment for the ecosystem. However, the calculation mode of ecological service functions of different ecosystems varies. When selecting an assessment method, it is necessary to give main considerations to the model’s scope of application, assessment accuracy, assessment prevision, data requirement, practices and application, and other elements. So, this study has tried to use classical quantitative model with higher accuracy and precision[9,12-13].

3.2.1. Assessment of Urban Ecological Service Functions. Millennium Ecosystem Assessment (MA) provides a conceptual framework of regional ecological system assessment. On the basis of classification of ecosystem service functions, including millennium ecosystem service[14] classification and Costanza[15]: main functions of the urban ecosystem services; and actual demands of the research area, this study has selected and assessed seven indicators: carbon fixation and oxygen release, retardant dust, nitrogen/sulfur purification, biodiversity protection, conservation of water and soil, water conservation, and leisure and entertainment. In addition, it has obtained 5-grade significance zones of seven ecological service functions, taking the highest grade of each indicator as the comprehensive assessment result of ecological function significance.

3.2.2. Evaluation of Urban Ecological Sensitivity. Ecological sensitivity refers to ecosystem’s capability to resist interferences caused by human activity and natural environmental changes. The level of sensitivity is used to gauge the risks and probability of ecological problems. In view of the ecological conditions and type of factors affecting Shenzhen’s ecological sensitivity, this study has selected and assessed three indicators, namely water and soil loss, habitat sensitivity, and water resource sensitivity. It has obtained 5-grade zones of three ecological sensitivities, taking the highest grade of each indicator as comprehensive assessment result of ecological sensitivity.

3.2.3. Comprehensive Integration and Delineation of Ecological Redlines. Considering the significance of ecological service functions and ecological sensitivity assessment results, this study delineated the ecological redline per the following steps:

   1) Step 1: Comprehensive Integration Analysis of Significance of Ecological Functions and Ecological Sensitivity: The maximum value of ecological function significance and ecological sensitivity assessment was taken as ecological protection grade. After integration, ecological protection grades IV and V were taken as the preliminary scope of ecological redline, namely achievement 1.

   2) Step 2: Analyzing Ecological Protection Plot Per Polygon Concentration: Achievement 1 was first changed into vector data. Later on, the aggregation surface tool in ArcGIS was employed to perform polygon aggregation. The aggregation distance was set at 250m, and the areas of both minimum hole and minimum polygon were set at 1km². Secondly, polygon concentration classification was made upon the vector result after aggregation according to polygon area. The threshold values of grading were divided as per the following table 1:

   | Polygon Area (Km²) | <0.25 | 0.25-0.5 | 0.5-1.0 | 1-2 | ≥2 |
   |-------------------|-------|---------|---------|-----|----|
   | Polygon Concentration | Low | Relatively Low | Normal | Relatively High | High |

   Later on, the vector result of ecological protection grade after aggregation was corrected by ecological polygon concentration, according to the following judgment matrix(table 2). For corrected results, area with “high” grade was taken as the corrected ecological redline scope, namely achievement 2.
Table 2. Table of Ecological Protection Correction Based on Polygon Concentration

| Ecological Protection Grade | Ecological Polygon Concentrations          |
|-----------------------------|-------------------------------------------|
|                             | High | Relatively High | Normal | Relatively Low | Low |
| Grade V                     | High | High            | High   | Relatively High| Relatively High |
| Grade IV                    | High | Relatively High | Relatively High | Relatively High | Normal |

(3) Step 3: Correcting Ecological Redline Based on Important Ecological Corridors: This study utilized polygon connectivity method and linear factor extraction to identify important ecological corridors. It included extremely important ecological corridors into the scope of ecological redline. Firstly, this study identified relatively feasible ecological corridors in view of the ecological corridor planning data, corridor layout, land utilization status of corridor and surrounding land, width requirement for corridors wider than 100m, and other factors. Secondly, this study identified important, large-scale, and connected ecological polygon as the ecological source based on the significance of ecological function and ecological sensitivity assessment results. It analyzed the significance and uniqueness of connectivity of relatively feasible corridors with source regions. It also analyzed the ecological conditions of the corridors. Later on, it extracted extremely important ecological corridors. Thirdly, this study included extremely important ecological corridors into the scope of ecological redline and obtained achievement 3.

(4) Step 4: Correcting Ecological Redline Based on Ecological Use Regulation Planning and Policy: The delineation of ecological redline needs to be linked with planning and policy of ecological use regulation zones in Shenzhen, such as natural reserves, water conservation districts, and natural parks. This study adopted core areas and buffer areas of natural reserves, special protection areas of first grade water conservation districts and scenic areas, and ecological protection core areas of geological parks to correct achievement 3 and obtain achievement 4.

(5) Step 5: Synchronizing Ecological Redline with the State of Construction and Future Demand for Urban Spaces: This study deducted existing construction lands from the lands required for large-scale key construction projects in the future. It carried out this task by taking into account the social development demand and land ownership, thereby correcting the scope of redline. This study mainly considered correcting the elements of construction status and obtained achievement 5.

(6) Step 6: Polygon Trimming in View of Natural Boundaries and Geographic Boundaries of Roads Using QuickBird High Resolution Images: The study further trimmed the edge of the broken polygon, besides ensuring that the scope of result did not include settlements and other elements, and finally delineated the ecological protection redline.

4. Analysis of Results

4.1. Assessment of Ecological Service Functions

Figure 2. Assessment of Significance of Shenzhen’s Ecological Functions
The assessment results (figure 2) show that Shenzhen has good overall ecological service functions. Therein, grade IV and V are extremely important ecological function areas, which are spread over 568.5 km² and account for 29.1% of the city. These areas are mainly mountain forest land. In addition, Grade III represents intermediate function areas spread over 308.5 km², accounting for 15.8% of the city. These are mainly gardens and other forest lands. Meanwhile, grades I and II are general ecological function areas spread over 1077.2 km², accounting for 55.1% of the city. These are mainly construction lands, parks, and greenbelts in built-up areas. In terms of specific ecological functions, biodiversity protection, N/S purification, conservation of water and soil, carbon fixation, and oxygen release are highly significant. In terms of spatial distribution, areas with extremely important ecological functions are mainly covered in mountain vegetation in the southeast and central Shenzhen. These pieces of important ecological lands, which are connected as blocks, are important constituent parts of the “matrix” in “matrix-corridor-polygon” ecological pattern. These are the core parts for building a complete ecosystem and ensuring ecological security of the city. These areas shall be included into the ecological redline and protected strictly in future.

4.2. Evaluation of Ecological Sensitivity

![Image of Ecological Sensitivity Map]

**Figure 3. Results of Evaluation of Shenzhen’s Ecological Sensitivity**

The assessment results (figure 3) show that areas with ecological sensitivity grades IV and V only cover 124.3 km², accounting for 6.4% of the city; Grade III areas cover 358.3 km², accounting for 18.3% of the city; while areas with ecological sensitivity grades I and II cover 1471.6 km², accounting for 75.3% of the city. Sensitive areas above intermediate grade have sporadic and patchy distribution, with higher spatial heterogeneity. Located in China’s southeastern coastal area, Shenzhen is characterized by warm and humid climate, gentle terrain, and highly built-up land. Therefore, the quantum of city’s overall ecological sensitivity is lower and spatial distribution is sporadic. At the same time, the type of ecological sensitivity shows obvious characteristics of a coastal city in eastern China. Specifically, the overall characteristics of spatial distribution show that sensitivity of eastern part is higher than that of the western part, sensitivity of areas with high terrain and steep slopes is higher than areas with gentle terrain, and sensitivity of areas with good vegetation coverage, good habitat environment, and centralized vegetation is higher than built-up areas covered by sporadic vegetation. Moreover, in terms of the type of ecological sensitivity, desertification and stony desertification are not included. The aforementioned areas with grades IV and V should be included into the scope of ecological redline and managed strictly in the future.

4.3. Results of Ecological Redline Delineation

After comprehensive integration, polygon aggregation, and boundary trimming per the significance of ecological functions and ecological sensitivity assessment results, the scope of ecological protection redline is finally delineated as 557.47 km², accounting for 28.53% of the entire city (figure...
According to spatial layout, the ecological protection redline is mainly distributed in mountainous and hilly regions in southeastern and central Shenzhen.

![Figure 4. Results of Ecological Redline Delineation in Shenzhen](image)

From the perspective of the relationship between the delineation scope and basic ecological control line, ecological redline accounts for 57.24% of the ecological control line (figure 2). From the perspective of spatial layout, 97.6% of the ecological redline is within the ecological control line. The delineation result effectively links and reinforces the management of ecological control line. As for the relationship between the delineation scope and land utilization status, the scope still includes 9.25 km² of construction land, including linear projects like roads, railways, and municipal facilities. Other sporadic facilities shall be converted to green land, or low ecological influence or low impact transformation shall be conducted in the future.

5. Discussion and Conclusions

5.1. Research on Ecological Redline Delineation is Highly Significant to Maintaining Urban Ecological Security and Building a System for Land Development and Protection

This study uses ArcGIS – a spatial analysis tool – to analyze and assess the ecological service functions, levels of ecological sensitivity, and ecological network pattern on the city and county levels. In this process, it also takes into account the control lines demarcated for various natural resources and spaces reserved for future urban development. In this way, it studies the ecological redline delineation of Shenzhen. This is one of the important contents of the “Three-District, Three-Line” delineation concept highlighted in national land planning in the new era. The ecological redline delineation provides spatial guidance and fundamental basis for subsequent management of natural resources, formulation of land use regulations, and hierarchical and classified management of the ecological space.

5.2. Indicators, Methods, and Technical Approaches of Studies Should be Scientific and Meet Local Demands

Ecological redline delineation is about the comprehensive classification of natural ecological resources. Therefore, this study focuses on three comprehensive points of planning when selecting assessment indicators and technical methods of delineation. (1) It is necessary to give full considerations to mountains, water areas, forests, farmlands, lakes, grasslands, natural environment, resource conditions, and management demands while determining ecological assessment and redline delineation methods from the aspects of quality of natural ecological resources, protection and utilization of ecological resources, and construction of ecological security pattern. (2) Coordination between regional and local areas is essential. Ecological system is required to be truthful, reliable, and systematic. Therefore, ecological assessment and ecological redline delineation need to be comprehensively planned and considered from a larger scale: regional and provincial levels. At the same time, it is necessary to pay attention to actual conditions of local ecological resources, particularly characteristic ecological
resources, like mangrove forests and wetlands. (3) Comprehensive plans linking the present with the future are required. The delineation of ecological redline should be based on objective ecological assessment of the status quo. In addition, the process of ecological redline delineation, as a regulatory tool, should give considerations to future urban development as well as the possible evolution of an ecological pattern.

5.3. Study Results Conform to Actualities of Local Ecological Environment Conditions and Urban Development
The core elements of ecological redline delineation are scale and layout. The scale of the entire urban ecological system, which includes the ecological redline, is usually estimated through ecological footprint and carrying capacity. However, at the core of the urban ecological system, this method is not suitable for delineating ecological redline, which is better delineated by actual and objective assessment of ecological functions and ecological sensitivity. Using this method, the scale of ecological redline has been delineated as 557.47 km². It is noteworthy that the scale actually reported by Shenzhen is based on indicators issued by the central government. It also takes into account the interests of the local and central governments as well as the city locals. Therefore, the scale of this reported redline is smaller than the scale of this study, and the layout has been adjusted accordingly.

5.4. Systematic and Integrated Ecological Security Pattern and Comprehensive Protection Are Essential to Urban Ecological Security
Ecological redline is only one important constituent of the urban ecological space. Urban ecological security can only be truly realized by protecting the urban eco-system, which includes the ecological redline, general ecological land outside the redline, and greenbelts in built-up areas.

5.5. Intensifying the Construction of an Ecological Redline System and Implementing Ecological Use Management Are Basis for Materializing Ecological Redline Delineation
The full-process monitoring of the ecological space can be realized by detailed planning of ecological units, hierarchal and classified management of ecological usage, ecological recovery measures, and coordinated management of “boundary, planning, policy, measure, and action”.

5.6. More Studies Are Needed for Developing an Automatic Analysis Platform for Delineation of Ecological Redlines and Marine Ecological Redlines
First, this study has used ArcGIS to assess 10 indicators, besides comprehensively integrating these assessments and carrying out polygon aggregation and trimming, among other data processing. This has been a time-consuming process as the analysis involved many parameters and a large quantity of data. In order to improve the efficiency and level of automation of these assessments, this study proposes exploring the development of a platform for ecological redline delineation. The platform may feature secondary GIS development, individual factor assessment, integrated assessment, and polygon aggregation. Furthermore, the national land space management for coastal areas covers both land and marine planning. Therefore, it is necessary to also investigate into and assess the marine ecological system and explore techniques for marine ecological redline delineation, thereby realizing whole-area all-element management of the ecological redline.

Acknowledgments
This study was financially supported by the research project of Urban Planning &Design Institute of Shenzhen (No. 2018ke04) and Key Laboratory of Urban Land Resources Monitoring and Simulation, Ministry of Land and Resources. Shenzhen(KF-2016-02-035)

References
[1] He YL, Huang HM, Chen J, et al. Overview of Ecological Redline System Construction Process of Our Country [J]. Ecological Economy, 2016, 32(9):135-139.

8
[2] Shi YJ, Wu XJ. Discussion on Normalization of Ecological Redline Concept [J]. Journal of South-Central University for Nationalities, 2016, 36(3): 149-153.
[3] Hu F, Yu YQ, Zheng Y, et al. An Innovative Study on Ecological Redline Delimitation [J]. Planners, 2018(5):108-114.
[4] Tian ZQ, Jia KJ, Zhang H, et al. Analysis on the Policy Evolution of Ecological Redline Delineation in China [J]. Ecological Economy, 2016, 32(9):140-144,156.
[5] Yan SG, Zhang H, Li HD, et al. Ecosystem Service Value of the Entire Land Area and Ecological Redlines in Jiangsu Province [J]. Acta Ecologica Sinica, 2017, 37(13): 4511-4518.
[6] Zhang Y. Research on Methods for Regional Ecological Redline Delineation [D]. Sichuan: Southwest University of Science and Technology, 2017.
[7] Li B, He JH, Qu Sai, Huang JL, et al. Delineating Method for Urban Ecological Redline Based on Bayesian Network. Acta Ecologica Sinica, 2018, 38(3): 800-811.
[8] Zhu KW, Lei B, He J, et al. Ecological Redline Delimitation Method at County Scale [J]. Ecology and Environmental Monitoring of Three Gorges, 2019, 4(01):34-42.
[9] Guidelines for the Ecological Protection Redline [S]. Ministry of Environmental Protection, National Development and Reform Commission. May 2017.
[10] Ye JT. Delineation of Ecological Redline on County Scale – A Case Study of Tonglu County [D]. 2016.
[11] Wang YC, Lv D, Peng ZW, et al. Delineation of Ecological Redline Based on Ecological Network Planning - A Case Study of Nanyi Lake Region in Anhui Province [J], Urban Planning Forum, 2015, 223(3): 28-35.
[12] Zhu JY, Mo LJ, Ye YC, et al. Study on Carbon Storage of the Forest Ecosystem in Dongguan [J]. Guangdong Forestry Science and Technology, 2011(02):22-29.
[13] Yu HQ, Li N, Lin PY, et al. Study on Dust Retention Effect of Common Landscape Plants in Shenzhen City [J]. Journal of Jiangsu Forestry Science & Technology, 2012(02):1-5.
[14] Finlayson M, Cruz R D, Davidson N, et al. Millennium Ecosystem Assessment: Ecosystems and human well-being: wetlands and water synthesis [J]. Data Fusion Concepts & Ideas, 2005, 656(1):87-98.
[15] Costanza R, Darge R, Groot R, et al. 1997. The value of the world’s ecosystem services and natural capital[J]. Nature, 387:253-260.