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A Framework for Exploring “Transfer-Out” Land Parcels for Urban Development Under the Ecological Control Line (ECL) Policy in China

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ABSTRACT

How to explore land spaces for future urban expansion under the ECL policy in China has been an essential issue. Previous methods or models just consider the land parcel's current land-use condition, while ignoring its future urbanization trend. This study proposes a framework for identifying the suitable “transfer-out” land parcels within the ECL by integrating the future urbanization probability and ecosystem services value. First, a vector-based cellular automata is adopted to determine urbanization probabilities of land parcels, and the ecosystem services values are evaluated based on the calculated equivalent table. Then, a “two-way screening” method is proposed to identify “transfer-out” land parcels by prioritizing the minimization of ecological value losses and the maximization of urban development benefits. The identified land parcels are evaluated at the suitability level by parcel connectivity analysis. The proposed framework was applied in Shenzhen, China. The results indicated that several “transfer-out” land clusters more suitable for planning as residential or public-service lands. This framework can provide global city planners with valuable policy guidance for dealing with similar ecological pressures.

1 | Introduction

Urbanization is a significant phenomenon affecting the global ecological environment (Henderson 2002; Deng et al. 2009; Johnson and Lichter 2020). Urban expansion creates more economic benefits and improves people's living standards (Tian et al. 2005; Gu, Hu, and Cook 2017), while it raises a series of ecological problems, including land degradation, forest reductions, soil erosion, and the greenhouse effect (Bren D'Amour et al. 2017; Xie et al. 2018; Bai et al. 2018). In the past 40 years, unprecedented advancements in the scale and rate of urbanization took place in China (Wang et al. 2012; Gu, Hu, and Cook 2017), giving rise to tremendous pressure on the ecosystem system and environmental resources (Seto, Guneralp, and Hutyra 2012; Vliet, Eitelberg, and Verburg 2017; Deng, Liu, and Fu 2019).

Ecological control line (ECL) policy is an important policy tool in China, which represents the boundaries of ecological control areas (ECAs) delineated by the government (Luo et al. 2018; Gao 2019). Since 2005, the ECL policy has been implemented in many large cities in China, including Shenzhen, Dongguan, Wuxi, Wuhan, Hefei, and Xiamen (Luo et al. 2018). ECAs play a “bottom line” role in preventing fast and disorderly growth of urban development and maintaining ecological safety (Chen et al. 2019; Chen, Zhao, and Wu 2019; Lin and Li 2019).

Except for the following five uses: (1) key roads and transportation; (2) public management and services; (3) tourist facilities; (4) green parks; (5) education and scientific research, and modern agriculture (Bai et al. 2016; Hong et al. 2017; Lin and While 2022), the lands within ECAs are prohibited from being converted to urban construction lands ("Regulations on the Management of Basic Ecological Control Lines in Shenzhen (amended in 2013)" policy). However, the conflict between the increasing land demands for urbanization and ECL policy is becoming more intense (Sheng 2010). Some megacities (each with a population of over 10 million) are facing a severe problem in that insufficient land resources cannot meet the space required for urban expansion. The restriction of land spaces has become a critical bottleneck for urban development (Zhao et al. 2006; Peng, Zhao, et al. 2017; Peng, Tian, et al. 2017; Jia et al. 2018).

In China, some cities have promulgated some policies to adjust Ecological Control Line for land space demands (Hong et al. 2017; Luo et al. 2018; Chen et al. 2019; Chen, Zhao, and Wu 2019). Shenzhen, as the first city to implement the ECL policy in China, formulated the "Optimization and Adjustment Plan of Shenzhen Basic Ecological Control Line" policy in 2013. This policy stipulates that ECAs can be adjusted reasonably with the demand for the construction of major projects related to the development of people's livelihoods (Hong et al. 2017). In 2020, the Ministry of Natural Resources of China established the "Opinions on the deepen reform in the natural resources in Guangdong-Hong Kong-Marco Greater Bay Area" policy. The policy allows Guangdong Province to optimize and adjust the three control lines of the territorial spatial planning (Ecological Control Line is one of the three control lines) during 2020–2035. It allows for the conversion of agricultural land outside of the permanent basic farmland into construction land (the ECAs contain a large amount of agricultural land), which with the approval authority, is decentralized to the Shenzhen Government. The policy also supports Guangdong Province in exploring the establishment of a mechanism for trading construction land within the province.

The ECL adjustment policies consist of two parts: "transfer-out" and "transfer-in." "Transfer-out" refers to transferring lands out of ECAs as the areas allowed for urban development (national, provincial, and city construction projects). "Transfer-in" refers to the transferring of lands into ECAs to strengthen ecological services functions. The basic principle is to maintain the "transfer-out" area to be equal to the "transfer-in" area and ensure that land parcels with high ecological quality remain within the ECAs. This study just focuses on the issue of "transfer-out" lands of the ECL adjustment in a megacity for which the lands are extremely scarce and such a shortage of available lands greatly impede sustainable urban development.

Many researchers have tried some studies about the policy management recommendations on adjusting and managing the ecological control line dynamically. Sheng (2010, 2012), Ouyang (2012) and Chen, Hong, and Yang (2018) summarized the problems and challenges faced by the implementation of ECL policy and tried to provide some urban green spatial planning and management new concepts. Li and Song (2014), He (2017), and Luo et al. (2018) explored the management measures of the ecological control lines integrating the object, pattern, implementation, and system to realizing the balance and comprehensive control among various sectors. Hong et al. (2017) proposed an ecological space management pattern that integrates the space system, management system, and support system in Shenzhen, and discussed how to balance between the rigorousness and flexibility of the ecological control line. Zheng (2018) explored an effective strategy merging ecological protection, rural development, agriculture transformation and leisure activity development to utilize the lands within the ecological control lines. Guan (2023) concerned the development dilemma of people living within the ecological control line, and pointed out the existing compensation systems are not sufficient to the loss of the land development rights. These studies almost provided recommendations on the ECL policy adjustment and management measures from theoretical perspectives, lacking spatially explicit solutions or technological methodologies for identifying specific adjusted land parcels. The "transfer-out" land parcels.

Some scholars tried to explore the practical solutions to identify "transfer-out" land parcels in the ECL adjustment program. The core ecological area is identified by spatially overlaying the seven categories of ecological protection sites, thus the areas with excluding out the core ecological area can be recognized as the transfer-out lands (Long 2009), then these lands be evaluated for transfer-out suitability grade by considering the surveyed land-use condition and residents' demand. Wang et al. (2012) identified "transfer-out" land parcels by screening out crucial ecological areas and priority selecting the lands located at the edge of the ecological control line, and appropriately meet the development needs of the local residents within the ecological control areas. These solutions have a complete technical framework that can be operated practically.

However, these studies have only considered the current land-use types of land parcels, while the future urbanization trends of land parcels have largely been ignored. The purpose of transferring out is to provide more spaces for future urban development where available land resources are too scarce. Thus, the future urbanization possibilities of land parcels must be taken as an essential basis when formulating an identification scheme of "transfer-out" land parcels.

One of the basic principles of transferring out is to ensure the high ecological quality lands remain inside the ECL. This means that the future urbanization trend and the ecological value should be considered equally important. How to balance ecological protection and future development in the land transfer-out scheme becomes a challenge. On the one hand, the land parcels with high ecological value should be retained within the ECL as far as possible to minimize ecological value losses. On the other hand, the land parcels with high future urbanization trends should be adjusted out to maximize the urban development benefits. Thus, under the certain number of land areas to be transferred out, it is crucial to prioritize the selection of land parcels with high urbanization probability and low ecological value from the ecological control areas.

This study proposes a new framework for identifying suitable "transfer-out" land parcels under the ECL policy. First, a vector-based cellular automata (VCA) model is adopted to project future land-use scenarios. The future urbanization probability of each land parcel is obtained by exploring the year-by-year transition probability using the VCA model. Then, the ecosystem services values of land parcels in ECAs are evaluated based on the calculated equivalent table. Finally, a "two-way screening" method is proposed to identify land parcels with high future urbanization probabilities and low ecosystem services values. These identified land parcels are assessed the suitability level for transferring out based on the parcel connectivity analysis. The proposed framework was applied to Shenzhen, one of the most land-constrained megacities in China.

2 | Study Area and Data

2.1 | Study Area

Shenzhen city is located in southern Guangdong Province in China, along the eastern side of the Pearl River and adjacent to Hong Kong (http://www.sz.gov.cn/cn/zjsz/gl/). Shenzhen is a rapidly urbanizing and highly developed metropolis with 10 administrative districts (Figure 1). The long-term resident population of Shenzhen is 11.91 million, and the actual population has reached 20 million (http://www.sztj.gov.cn/). However, the area of Shenzhen is only 1997.47 km^2 (12.17% of Beijing, 31.50% of Shanghai, and 26.76% of Guangzhou). Shenzhen is suffering tremendous pressures, including a vastly dense population, severe shortage of land resources, restricted urban development space, and insufficient resource capacities (Qian et al. 2016; Huang et al. 2019).

To protect urban ecosystems and prevent unreasonable urban sprawl, Shenzhen became the first region in China to designate ECAs in 2005. The area of ECAs is 974 km^2, constituting 48.76% of the city (Figure 1). The ECL policy has exacerbated the scarcity of land space available for urban development which has an obvious constraining influence on the development of commercial and industrial projects (Sheng 2012; Hong et al. 2016). The construction land allowed for urban expansion in Shenzhen is approaching its upper limit.

2.2 | Data

This study adopted vector land-use data, driving factors data and ECAs data in Shenzhen. The details about data are shown in Table 1. Among them, the vector land-use data and driving factors data are used for land-use change simulations. The ECAs data are used to project the future land-use scenario guided by the ECL policy.

3 | Method

As shown in Figure 2, the proposed framework for identifying the suitable "transfer-out" land parcels involves four parts. (1) Urbanization probability by CNN-VCA: Urbanization probability is derived from CA model projections based on the historical land-use change trends. The future urbanization probability of each land parcel is obtained by exploring the year-by-year transition probability using a convolutional neural network (CNN)-based VCA model (Zhai et al. 2020). (2) Projected future land-use scenarios: The future land-use in 2050 under the ECL-guided scenario is projected using the calibrated CNN–VCA model. The land-use pattern in 2050 under the baseline development scenario is also simulated for comparison. (3) Evaluation of ecosystem services value: The ecosystems services value of each land parcel is evaluated based on the equivalent value coefficients table and the calculated one equivalent value (Xie et al. 2008; Liu, Zhang, and Zhang 2014). (4) Identifying "transfer-out" land parcels and suitability level assessment: A "two-way screening" method is proposed to identify "transfer-out" land parcels. Land parcels are selected to minimize ecological value losses in one way

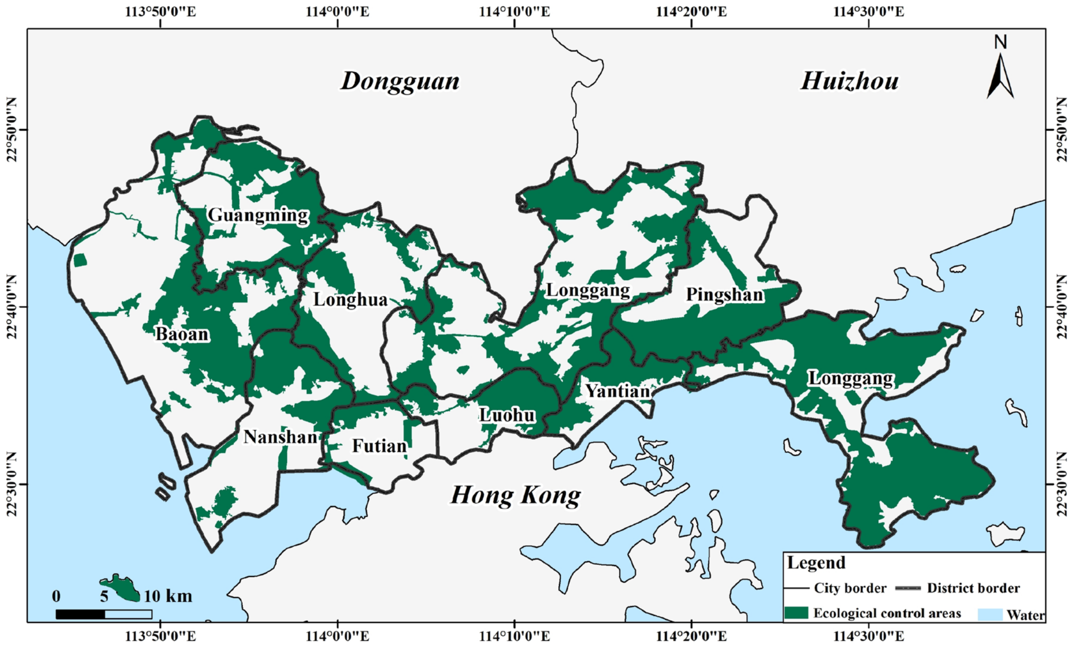


FIGURE 1 | Shenzhen city and its ecological control areas (ECAs).

TABLE 1 | List of data used in this study.

Category	Data	Type	Data resource
Land use	Cadastral land-use data (2009 and 2014), including five categories: nonurban land, public-services land, commercial land, residential land, and industrial land	Vector	Bureau of Land and Resources of Shenzhen
Driving factors	Basic topographic data (DEM and slope)	Raster (30-m resolution)	Geospatial Data Cloud (http://www.gscloud.cn)
	Location and transportation (the distance to district centers, the distance to railways, the distance to highways, and the distance to main roads)		Calculated from land-use data and traffic road data
	Density of point of interest (POI) (hospitals, bus stations, restaurants, entertainment facilities, parks, supermarkets, shopping malls, and factories)		Gaode Map API (https://www.amap.com/)
Ecological control areas	Ecological control line	Vector	Bureau of Land and Resources of Shenzhen

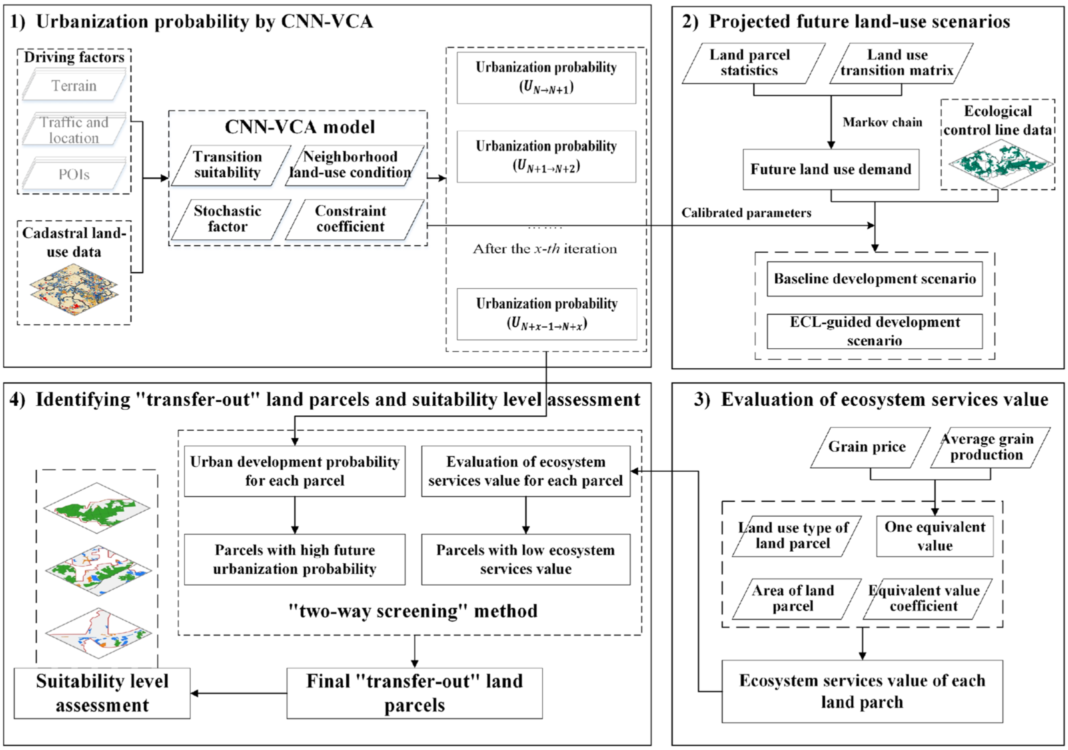


FIGURE 2 | Proposed framework for identifying the suitable "transfer-out" land parcels.

and to maximize the urban development benefits in the other way. Then, these identified "transfer-out" land parcels are assessed its suitability level: high, medium, and low.

3.1 | Urbanization Probability by CNN-VCA

Cellular automata (CA) model is a widely used methodological approach to simulate complex processes such as land cover and land-use change (Li et al. 2017). CA models mainly include four parts: the transition suitability, the neighborhood land-use condition, the constraint coefficient, and the stochastic factor (Li and Yeh 2002). CA models can effectively uncover the historical urban evolution pattern and simulate future urban development trends. Some researches, taking CA model as part of the whole framework, aims to address typical urban problems, such as urban growth boundaries, ecological impacts of different urban evolution patterns, and early warning of illegal development in ecological zones (Li et al. 2013; Li and Zhao 2017; Chen et al. 2019; Chen, Zhao, and Wu 2019).

Raster-based cellular automata (RCA) models use regularly shaped and sized grids as basic units (i.e., cells). However, most land-use policies and regulations set by the government are based on irregularly shaped land parcels with clear boundaries and absolute ownership. Vector-based CA (VCA) models, which adopt irregularly shaped vector polygons as cells to represent irregular parcels, have been applied to excavate the land parcel's transition probabilities from nonurban use to urban use, and project multiple future land-use scenarios at the land parcel scale (O'Sullivan 2001; Stevens and Dragićević 2016; Yao et al. 2017).

This study adopts the CNN-VCA model to explore the future urbanization probabilities of land parcels by accumulating the transition probability of each land parcel. The CNN–VCA model (Zhai et al. 2020) is a framework that integrates the CNN method into the VCA model to simulate the land-use changes at the land parcel scale. The CNN was used to extract the high-level features of the driving factors within the parcel's neighborhood and discover the relationships between multiple land-use changes and driving factors. The simulated results show that CNN–VCA model could obtain the highest simulation performance in comparison with other VCA models. More details about the CNN–VCA model can be found in Zhai et al. (2020). In this study, the CNN–VCA model showed high accuracy through land-use change simulation during 2009–2014 (see the Supporting Information).

In the CNN–VCA model, the transition probability (P) of each land parcel is generated by the combination of transition suitability (P_g), neighborhood land-use condition (Ω), constraint coefficient (P_c), and stochastic factor (RA). More detail about the formula can be found in Zhai et al. (2020). The urbanization probability (U) of each land parcel is calculated as follows:

$$U_i^t = \sum P_i^{k,t} \tag{1}$$

where U_i^t refers to the urbanization probability of cell i at time t, k is the possible land-use change type of cell i, including four categories: nonurban to public-services land, nonurban to commercial land, nonurban to residential land, and nonurban to industrial land. The neighborhood land-use condition (Ω) depends on the quantity and type of nearby land parcels, which change with urban expansion. This means that the urbanization probability of each land parcel also changes yearly with urban development. The constraint coefficient (P_c) is a parameter that controls whether a land-use type change to another type is allowed. The restricted development area is 0, and the allowed development area is 1. The iteration step of the CNN-VCA model is set to 1 year. The process of exploring the urbanization probability of each cell year by year is shown in Figure 3.

The starting year of the land-use change process is set as N, and the target year is set as $N+x$. After one iteration, the urbanization probability of each land parcel from year N to $N+1$ can be calculated. The simulated land use in year $N+1$ can also be obtained, which is then used as an input to the CNN–VCA model to continue the second iteration. The neighborhood land-use condition (Ω) in year $N+1$ is then recalculated. Thus, after the *x-th* iteration, the urbanization probability from the year $N+x-1$ to $N+x$ is obtained. Finally, the future urbanization probability of each land parcel in the target year is calculated by accumulating the urbanization probability obtained each year. The formula is as follows:

$$U_{i(\mathrm{N}\rightarrow\mathrm{N+x})} = U_{i(\mathrm{N}\rightarrow\mathrm{N+1})} + U_{i(\mathrm{N+1}\rightarrow\mathrm{N+2})} + \ \dots \ + U_{i(\mathrm{N+x-1}\rightarrow\mathrm{N+x})} \tag{2}$$

where $U_{i(\mathrm{N}\rightarrow\mathrm{N+x})}$ is the future urbanization probability of cell i from starting year N to target year $N+x$.

3.2 | Projected Future Land-Use Scenarios

One of the primary purposes of this study was to explore how many years the existing land space can support urban growth under the strict ECL policy. This study developed two future land-use scenarios: (1) a baseline development scenario, and (2) an ECL-guided development scenario. The two predicted scenarios are compared to analyze the ECL policy's effect on future urban land-use patterns. These scenarios are described below.

1. Baseline development scenario: Shenzhen's future land-use change will follow the historical pattern during 2009–2014, and no land-use policies will be considered to promote or constrain the urban growth rate. This means that in this scenario, the ECL policy will not be considered, and no parameter adjustments will be made to the CNN–VCA model.
2. ECL-guided development scenario: The future land use of Shenzhen is guided by the strictly constrained strategy of the ECL policy. The land within ECAs is prohibited from being developed into construction land. In this scenario, the constraint coefficient parameters of the CNN–VCA model are adjusted under different conditions (Figure 4). Land parcel A intersects with the ECAs and is then divided into two parcels: parcel A_1 is within the ECAs, and parcel A_2 is out of the ECAs. Thus, parcel A_1 is not allowed to be developed, meaning its constraint coefficient is adjusted to 0.0, while the constraint coefficient of parcel A_2's is adjusted to 1.0. Land parcel B is located inside the ECAs, and its constraint coefficient is 0.0. Land parcel C is located outside the ECAs, and its constraint coefficient parameter is 1.0.

A Markov chain (Kamusoko et al. 2009) is used to generate the conversion probability of multiple land-use types over a time series and then to calculate the quantitative structure of land-use changes in future periods.

$$S_{ij(t+1)} = P_{ij} S_{i(\mathrm{t})} \tag{3}$$

where $S_{ij(\mathrm{t+1})}$ is the area of land-use type i converted to type j at the future time $t+1$, $S_{i(\mathrm{t})}$ is the area of land-use type i at the time t, and P_{ij} is the probability that land-use type i transitions to type j.

In this study, the annual conversion probabilities of multiple land-use types were calculated by the land-use change transfer matrix from 2009 to 2014. Then, a Markov chain was used for generating the future land-use demand. The projected future

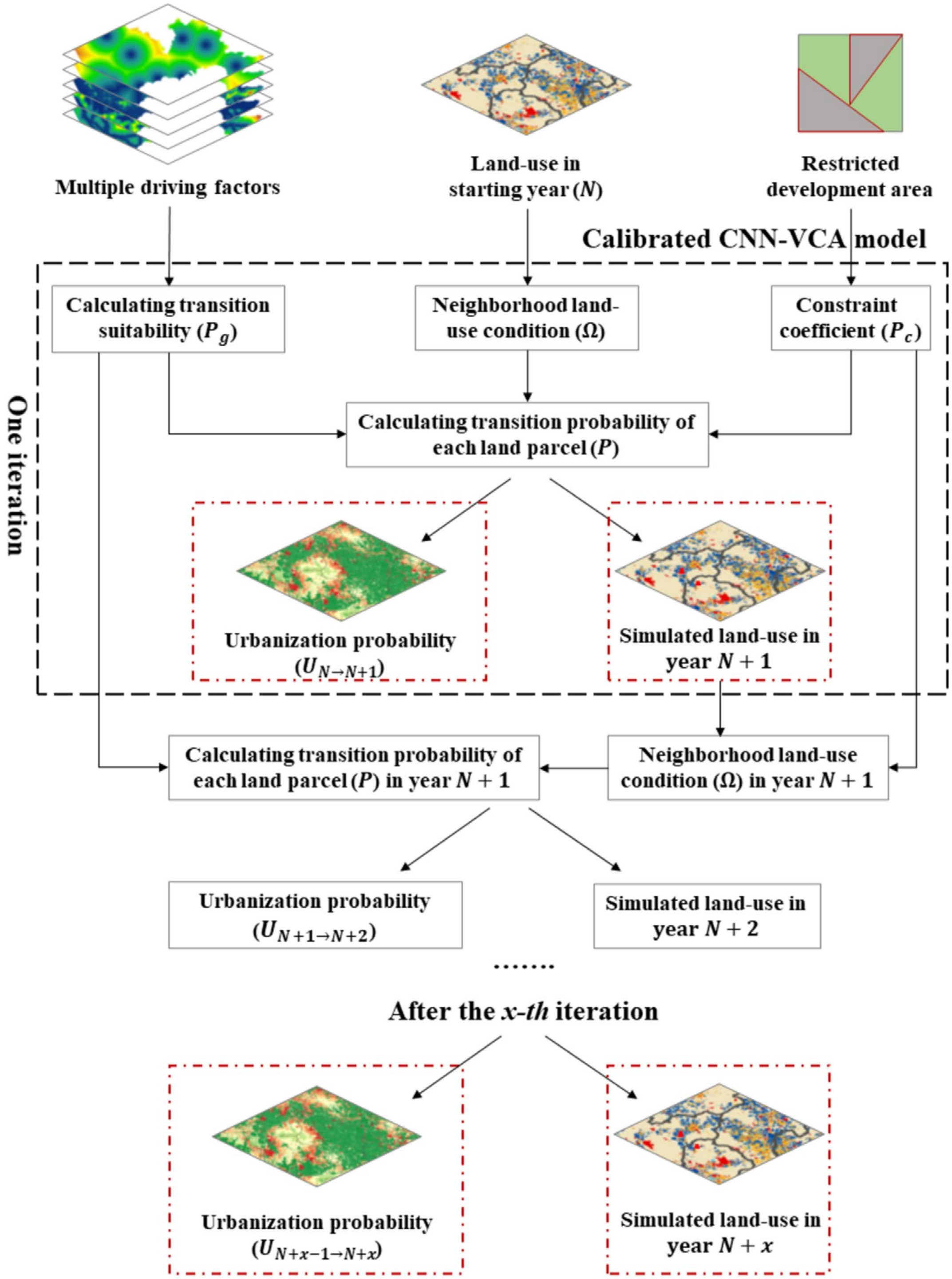


FIGURE 3 | Exploring the year-by-year urbanization probabilities of land parcels.

land-use demand was used as the total amount condition in the CNN–VCA model to predict future land-use patterns yearly during 2014–2050 under different annual scenarios.

3.3 | Evaluation of Ecosystem Services Value

Selecting land parcels with low ecological services values within ECAs is one of the key components of identifying suitable "transfer-out" lands. Therefore, it is essential to evaluate ecosystem services value at the land parcel scale. Ecosystem services (ES) represent various ecosystem functions referring to the habitat, biological, or system properties or processes of ecosystems (Costanza et al. 1997). In China, Xie et al. (2003, 2008) classified the ES into nine categories, including food production, raw materials, gas regulation, climate regulation, water regulation, waste treatment, soil maintenance, biodiversity protection, and landscape aesthetics, and established the Chinese equivalent value coefficients table to evaluate the ecosystem services value (ESV). The equivalent value coefficient represents the relative contribution of the potential ecosystem services, and one equivalent value could be equal to 1/7 of grain price per hectare per year (Li, Li, and Qian 2010; Liu, Zhang, and Zhang 2014). According to the Shenzhen Statistical Yearbook for 2018, the average grain production in Shenzhen between 2010 and 2017 was 7095 kg/hm^2, and the grain price in 2017 was 2.72 yuan/kg. Thus, one equivalent value is calculated as 2756.91 yuan/hm^2.

Then, based on the table of equivalent value coefficients modified by Xie et al. in Xie et al. 2008 (see Table S1), the table for ecosystem services value per km^2 for different land-use types in Shenzhen is obtained (see Table S2). The total ecosystem services value of a given area is calculated as follows:

$$\text{ESV} = \sum \left(A_k * \text{VC}_k\right) \quad (4)$$

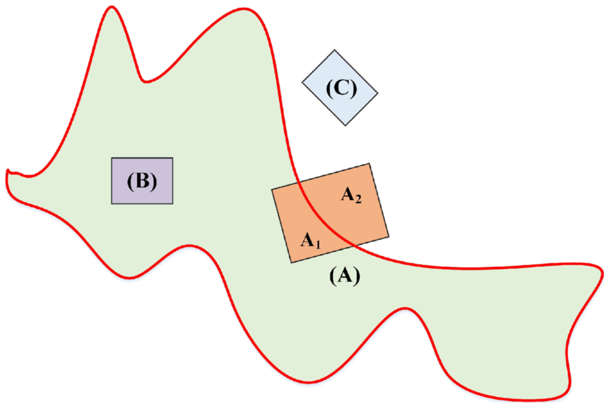


FIGURE 4 | Spatial relationship of land parcels with the ECAs: (A) Intersection, (B) Inside, and (C) Outside.

where ESV is the ecosystem services value, A_k is the area of land-use type k, and VC_k is the ecosystem value for land-use type k.

3.4 | Identifying "Transfer-Out" Land Parcels and Suitability Level Assessment

A "two-way screening" method is proposed to identify "transfer-out" land parcels (Figure 5). Land parcels are selected to minimize ecological value losses in one way and to maximize the urban development benefits in the other way. Then, these identified "transfer-out" land parcels are evaluated its suitability as three level: high, medium, and low.

In the "two-way screening" method, the total area of the "transfer-out" land parcels is set as TargetArea; this value is set flexibly based on the spatial demand for future urban development. In this study, TargetArea is equal to the urban development space demand in 2050 calculated by the Markov chain minus the existing land space.

The screening procedure includes multiple iterations. In the first iteration, the land parcels minimizing ecological value losses include follows:

$$\text{PE} = \left\{ \text{P}_\text{i} \mid \text{E}_\text{i} \in \text{MIN} \bigwedge \text{Con}(\text{TransferOut} < \text{TargetArea}) = 1 \right\} \quad (5)$$

where PE is a collection of land parcels with minimum ecological value losses, P_i is the land parcel i. E_i is the ecosystem services value of land parcel i, $\bigwedge$ represents the logical operation "and".

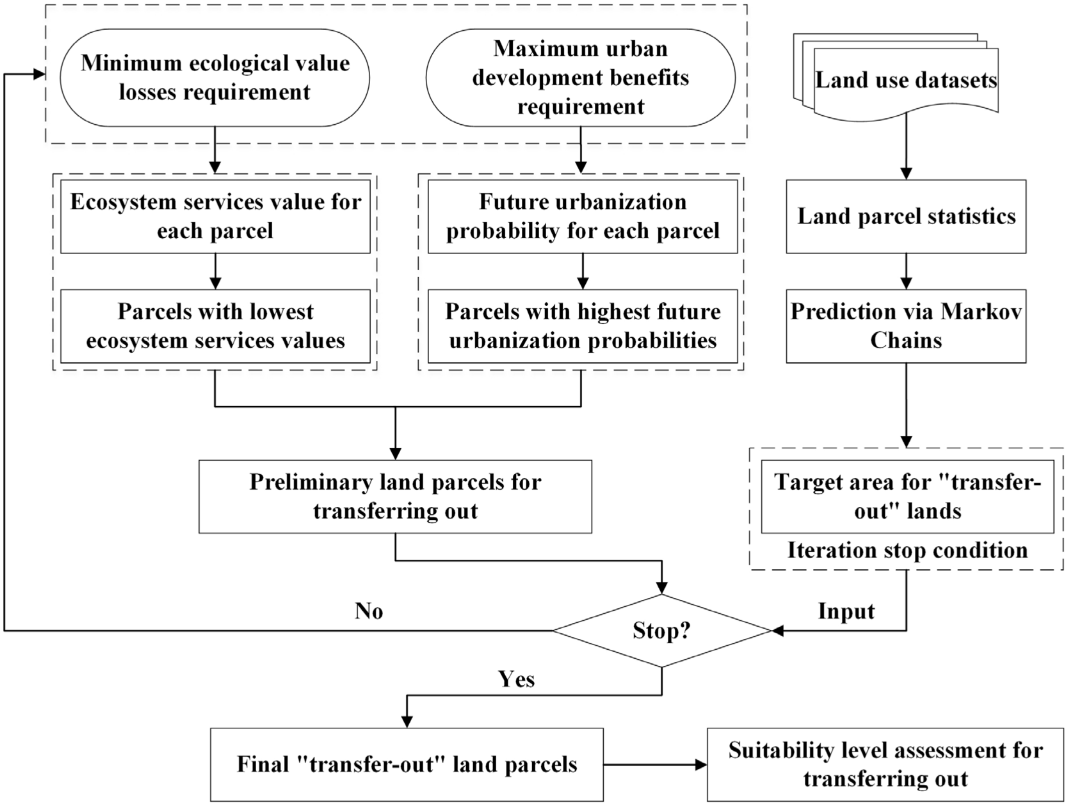


FIGURE 5 | Flowchart of the "two-way screening" method for identifying "transfer-out" land parcels and the suitability level assessment.

MIN is the land parcel set with the lowest ecosystem services values in this region, Con is a conditional function that returns a value of 1 if the condition is met and 0 if not, and TransferOut represents the areas of the identified "transfer-out" land parcels. When TransferOut is less than TargetArea and the ecosystem services value of parcel *i* is subordinate to MIN, the land parcel set PE with the minimal ecological value losses is formed.

The land parcels with maximum urban development benefits can be described as follows:

$$\mathrm{PU} = \left\{ \mathrm{P_i} \mid \mathrm{U_i} \in \mathrm{MAX} \bigwedge \mathrm{Con(TransferOut < TargetArea)} = 1 \right\} \tag{6}$$

where PU is a collection of land parcels with maximum urban development benefits, P_i is the land parcel *i*. U_i is the future urbanization probability of land parcel *i* in the target year. MAX is the land parcel set with the highest future urbanization probabilities in this region. When TransferOut is less than TargetArea, and the future urbanization probability of parcel *i* is subordinate to MAX, the land parcel set PU with the maximum urban development benefits is formed.

Then, the land parcels under the set PE are ranked from the lowest ecological value to high and sequentially encoded. The land parcels belong to the set PU are ranked from the highest urbanization probability to low and sequentially encoded. The total area of land parcels of set PE is less than TargetArea, so is set PU. Then, the land parcel encoded 1 in the set PE is firstly selected, and be judged whether it is under the set PU, and if it is, then the land parcel will be marked as "transfer-out". Repeat the above selecting process until all the land parcels in the set PE are judged, then the first iteration stops.

After one iteration, the total area of identified "transfer-out" land parcels is smaller than TargetArea. Thus, multiple iterations must be conducted by compromising the conditions, to include the land parcels with the second-highest future urbanization probabilities into the set MAX and the land parcels with the second-lowest ecosystem services values into the set MIN.

In the second iteration, the land parcels marked "transfer-out" in the first iteration are exclude, and all the rest land parcels are screened with the same selection process above repeatedly. The sets MAX and MIN are compromised alternately, and the set PE and PU will be updated. As a result, some additional land parcels will be identified as "transfer-out" land parcels.

The iteration process is repeated until the total area of identified "transfer-out" land parcels reaches TargetArea; then the iteration stops.

The suitability level of "transfer-out" land parcels is assessed by parcel connectivity analysis. Parcel connectivity depends on the amount and total area of topologically contiguous land parcels (Zhou et al. 2008). First, land parcels were determined whether topologically contiguous or not; if so, the parcels were fused as a larger contiguous parcel. Then, a corresponding relationship table was obtained that included the ID of the fused contiguous parcel, the area of the fused contiguous parcel, the number of original parcels for each fused contiguous parcel, and the IDs of the original parcels for each fused contiguous parcel (Figure 6).

The suitability level of "transfer-out" land parcels is assessed at three levels: high, medium, and low. If one land parcel was part of a fused contiguous parcel and the area of the fused contiguous parcel was in the top 10% of all contiguous land parcels sorted from largest to smallest (i.e., due to the significant advantage of a large area size), the parcel's suitability for transferring out is high. When in the top 10% to 50% (i.e., due to the advantage of an average area size), a parcel's suitability for transferring out was medium. If a land parcel was in the bottom 50% (i.e., with a small area size) or was not contiguous with other parcels, the parcel's suitability for transferring out was low.

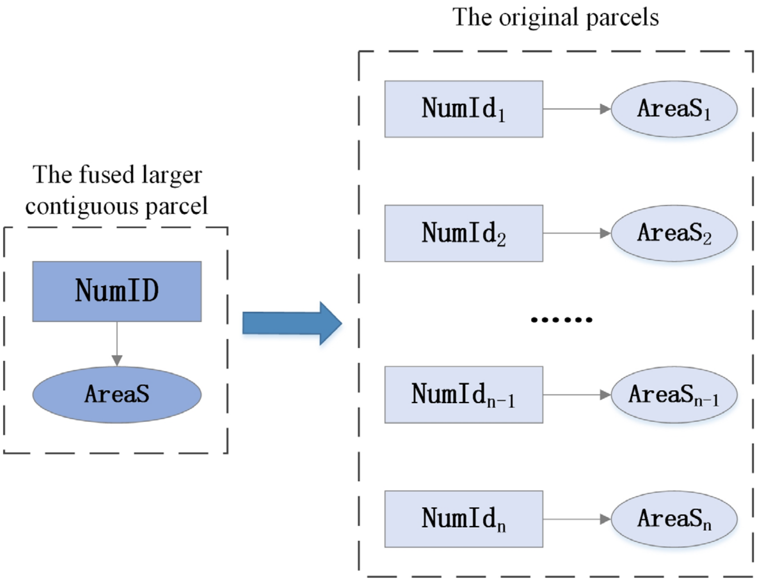


FIGURE 6 | Fused larger contiguous parcel and its original parcels.

4 | Results

4.1 | Scenarios of Future Land-Use Changes From 2014 to 2050

Based on the two projected future land-use scenarios, the CNN–VCA model was implemented to generate future land-use patterns. As the essential policy background, the “Optimization and Adjustment Plan of Shenzhen Basic Ecological Control Line” policy was proposed by the Shenzhen government in 2013. Thus, the year 2014 was chosen as the starting year in the simulated future land-use change scenarios in this study. Two scenarios and some typical areas of newly added urban lands are presented below from 2014 to 2050 (Figure 7).

1. Baseline development scenario

The newly added urban lands that are generally characterized mostly sprawl around the available constructed lands and traffic roads in Shenzhen. Most newly added industrial lands exhibit aggregated spatial distribution and are constantly expanding along the edges of existing industrial parks. Many of the newly added residential lands are contiguous with the newly added industrial lands and grow along the developed industrial lands and residential clusters. The simulated results show that under the baseline development scenario, the ecological lands (cultivated land, forestland, grazed land, and unused land) located in the neighborhoods of built-up lands and traffic roads are given priority for conversion to urban land. This indicates that the main driving forces of the future urban development of Shenzhen are the attraction of public transportation and the industrial agglomeration effect of the built-up area downtown. This finding is consistent with the result of other studies on the urban growth of the Pearl River Delta region (PRD) in China (Liang et al. 2018).

In this scenario, 62.22% of the newly added urban lands will be within ECAs, with a total area of 196.43km^2. This means that large numbers of land parcels with high urban development probabilities are within ECAs. Among the four nonurban–urban conversion types within ECAs, the conversion to public management-services land has the largest area proportion, accounting for 42.68%. These lands are almost entirely distributed in the Nanshan, Futian, Luohu, and Yantian districts as the old downtown of Shenzhen, which are with small clusters in locations close to the existing public management-services lands. Only 7.67% of the newly added urban lands are commercial lands, and these lands are almost entirely located in the central and southeastern part of Dapeng district (Figure 7, (I)). These lands are concentrated along the main traffic roads, and their surroundings are dominated by tourism industries, such as resort hotels, bed and breakfast hotels, guest houses, and sailing clubs. Actually, the existing commercial lands are mostly distributed in the Futian, Luohu, and Nanshan District, which are highly urbanization and developed districts of Shenzhen. Affected by the main driving forces of future urban expansion, many of the newly added commercial lands should be located within these districts. However, there is not sufficient land space available for continuous commercial expansion. Thus, large amounts of the newly added commercial lands are shifted to other districts that have sufficient land space for development.

2. ECL-guided development scenario

In this scenario, all of the newly added urban lands are located outside of ECAs, with a fragmented distribution of spatial land-use patterns. The conversion of nonurban to industrial land is constrained by the ECL policy, especially in the Baoan and Longgang districts, which are the concentrated industrial park areas of Shenzhen. Figure 7 (II, d) shows that large numbers of land parcels are contradictory to industrial expansion and ecological protection, that is, these parcels have high probabilities of being converted from nonurban land to industrial land, but are forbidden from being developed because they are within ECAs. Similar to the baseline development scenario, the newly added residential lands are distributed in neighborhoods within developed industrial lands and residential clusters and along the intersected transportation routes. As the ecological special zone of Shenzhen, Dapeng district is rich in natural resources, with several nature reserves and forest parks. Large area of Dapeng district is delimited within ECAs. In the ECL-guided scenario, the newly added commercial land overexpansion trend under the baseline development scenario was significantly contained (Figure 7 (II, b)), and the natural forests and coastal beaches in the area were protected well.

The predicted results indicate that strict ecological protection has an obvious constraining effect on nonurban-urban conversions. As stated in the simulated results (Figure 8), there will be no available land in Shenzhen for urban expansion after 2041 in the ECL-guided scenario. This means that the nonurban land allowed for urban development will be exhausted by 2041, and the urbanization of Shenzhen will reach an “upper limit”.

4.2 | Identified the Suitable “Transfer-Out” Land Parcels

The probability of each land parcel transitioning from nonurban land to urban was extracted year by year via the CNN-VCA model. These results were then used to calculate the future urbanization probability cumulatively for each land parcel in a particular year in the future. Using the natural breakpoint method, the future urbanization probability of each land parcel was classified into seven degrees: lowest, low, medium-low, medium, medium-high, high, and highest. According to the statistics, at present, 35.28% of the area within ECAs has urban development suitability above a medium-high level. In addition, 79.59% of these areas are land parcels with medium-high and high levels, and highest suitability parcels comprise 20.41%. Overall, the future urbanization probabilities of land parcels within ECAs are presented by high edges and low centers in their spatial distributions (Figure 9A). This may result from the strong attraction of the existing built-up areas situated around the edges of the ECAs.

The evaluation of ecosystem services value at the land parcel scale was achieved based on a calculated equivalent table of ecosystem services value per km^2 of different land-use types in Shenzhen. Similarly, each parcel's degree of ecosystem services value was classified into seven degrees: lowest, low, medium-low, medium, medium-high, high, and highest

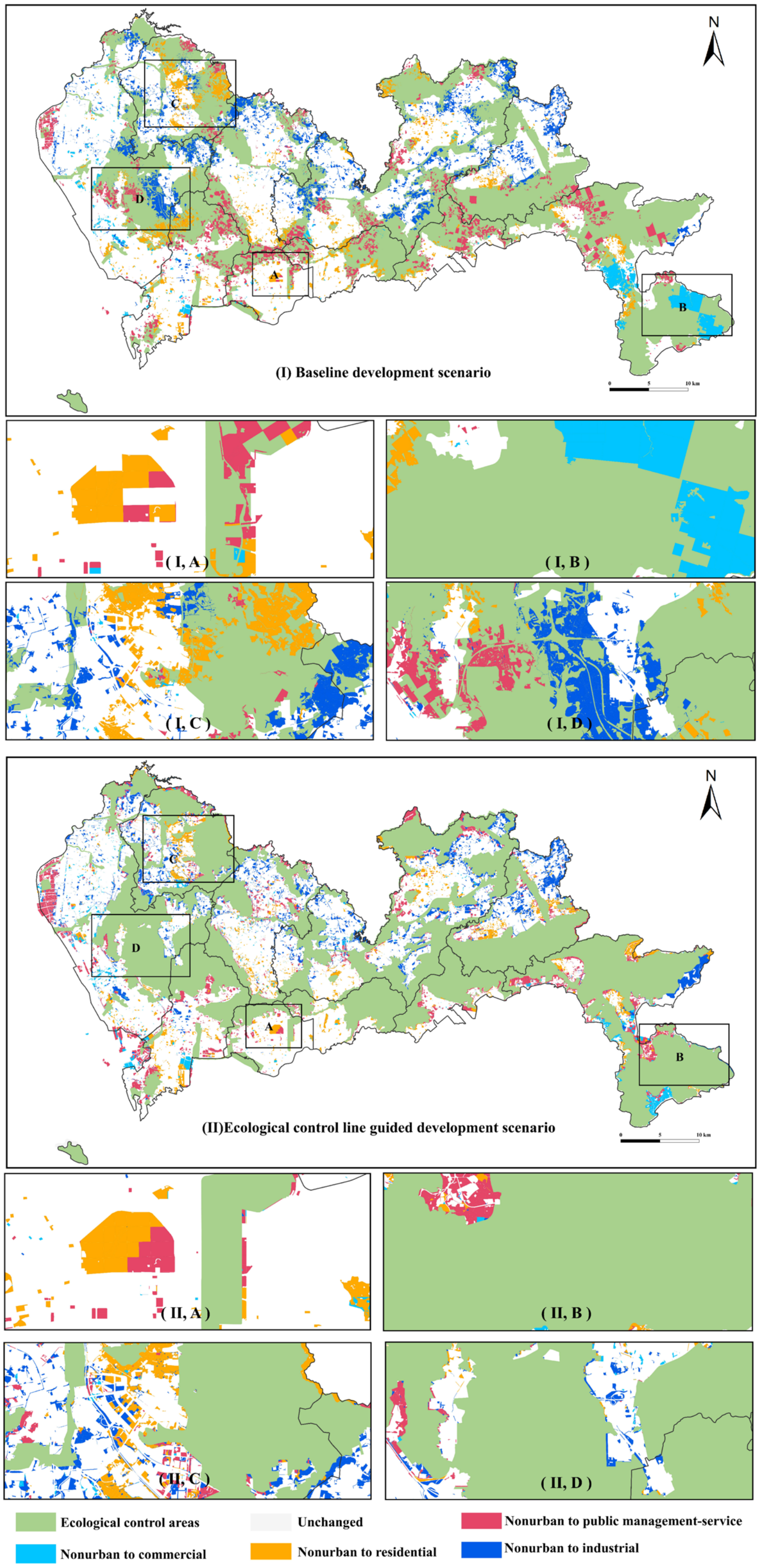
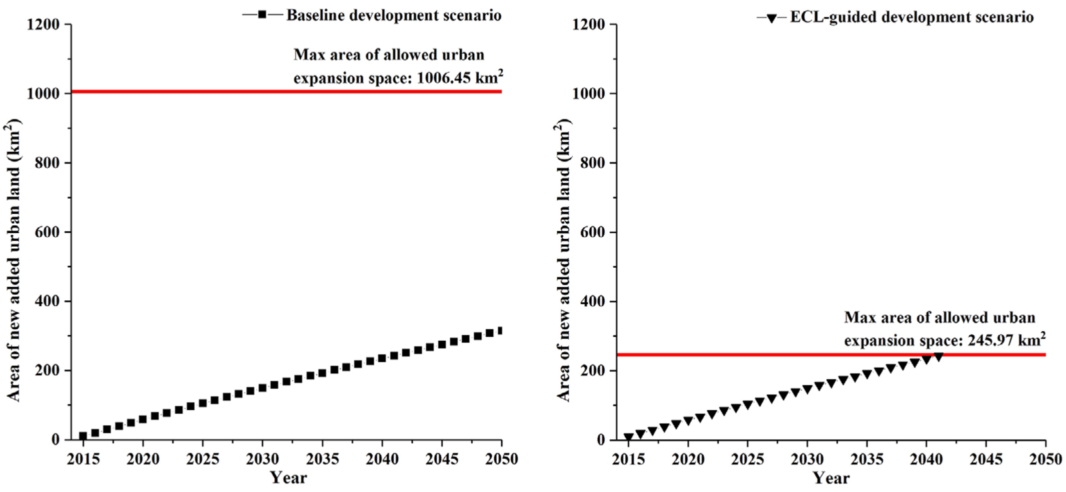


FIGURE 7 | Comparison of simulated land-use changes from 2014 to 2050 under the (I) Baseline development scenario and (II) Ecological control line guided development scenario. (A) Typical areas of newly added public management service land, (B) typical areas of newly added commercial land, (C) typical areas of newly added residential land, and (D) typical areas of newly added industrial land.

(Figure 9B). The ecosystem services values of land parcels within ECAs have low-western and high-eastern spatial distributions, consistent with the spatial patterns of the natural resources in Shenzhen.

The results of the identified "transfer-out" land parcels within ECAs are shown in Figure 10. The total area of "transfer-out" lands is 69.55 km^2, comprising land areas both with high future urbanization probabilities and low ecosystem services values.



(A) The trend of newly added urban land under baseline development scenario

(B) The trend of newly added urban land under ECL-guided development scenario

FIGURE 8 | Growing trends of newly added urban land from 2014 to 2050 under different scenarios.

The land-use types of "transfer-out" lands are unutilized land (including bare land, and vacant land), and agricultural land (irrigated land and orchard land). In terms of their spatial distribution, most of the "transfer-out" lands are distributed at the western edges of ECAs, while small areas of scattered land are located in the centers of ECAs, and barely any land is in the eastern parts.

The suitability of "transfer-out" lands parcels was assessed at three levels: high, medium, and low (Figure 10). The area of "transfer-out" land parcels with high suitability accounts for 63.03% of the total area, and the parcels are relatively concentrated in their spatial distribution. The contiguous "transfer-out" land parcels with high suitability have several clusters larger than 1 km^2. Most of these clusters are concentrated in the Nanshan district (Figure 10A) and Guangming district (Figure 10B). Derived from the projected future land-use scenarios, these contiguous "transfer-out" land parcels with high suitability in Nanshan district should be developed into residential and public-service lands under the baseline development scenario. If these land parcels are transferred out of ECAs by the government, they can be considered in urban planning as residential clusters and areas supporting public-services lands. Approximately 21.69% of the "transfer-out" land parcels are of medium suitability and are scattered with small contiguous areas in the Baoan, Guangming, and Longgang districts.

5 | Discussion

To effectively estimate the "transfer-out" land parcels' urbanization trends under the ECL policy, this study proposes a new framework considers the land parcels' future urbanization probabilities converted to different urban land-use types. This framework integrates the exploration of future urbanization probabilities and an evaluation of the ecosystem services values of land parcels. The proposed framework can provide support for the dynamic management of ECAs in practice, aiming to realize the maximization of urban development benefits and the minimization of ecological value losses. In this study, the proposed framework was applied in Shenzhen, one of the most land-constrained megacities in China.

The results show that the lands currently available for the urban development of Shenzhen will be exhausted by 2041 under the strict ECL policy. The existing land space of Shenzhen is very limited far away from the land-demand area for the nearly 20 million people in this city. Previous studies have shown that Shenzhen is suffering from the conflict between urban development and ecological protection (Shi and Yu 2014; Peng, Zhao, et al. 2017; Peng, Tian, et al. 2017; Hu et al. 2020). Since the ECL policy was implemented in 2005, the area of nonurban land allowed for urban development in Shenzhen has been reduced, which has even exacerbated the seriousness of the above issue (Hong et al. 2017). Under the ECL-guided development scenario, the nonurban land allowed for urban development in Shenzhen will last to 2014 under the current urbanization trend. This means that the government needs to make adjustments to support long-term sustainable development.

The identified "transfer-out" lands based on the proposed framework are relatively concentrated in their spatial distribution. Several large areas of contiguous "transfer-out" land parcels are located in the Nanshan and Guangming districts. Previous studies have shown that large-scale projects guided by the government are often several square kilometers or even larger, and require large numbers of contiguous land parcels (Zhou 2017). The continuity degree of the spatial distribution of land parcels directly affects the costs and benefits of land-use activities, and contiguous land parcels are conducive to the economic and intensive utilization of land resources (Zhang and Zhang 2008; Stewart and Janssen 2014). As stated in our results, the identified contiguous "transfer-out" land parcels in Nanshan district should tend to develop into residential and public-services land. When government departments plan districts in the future, these land parcels could be designed as residential clusters or public-service lands.

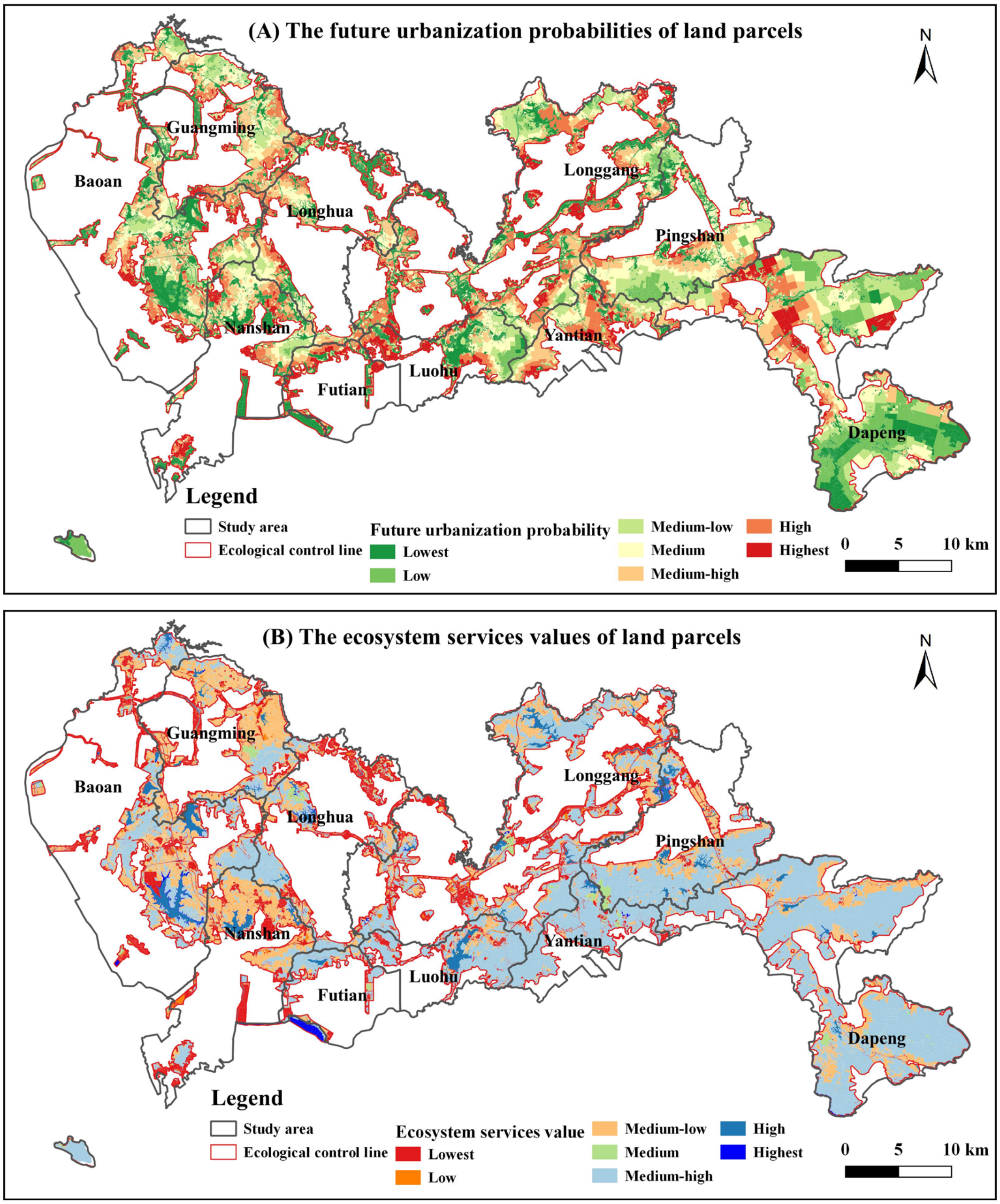


FIGURE 9 | Future urbanization probabilities and ecological services values of land parcels.

The contributions of this study are mainly in two aspects: First, this study can provide local land resource-concerned governments with scientific support at the practical level for ECA adjustments. The proposed framework provides a practical solution for decision makers to make plans for "transfer-out" land parcels. These results can also be taken as an essential part of the elements required for evaluating the reasonableness of "transfer-out" lands applied for urban development projects. These identified suitable "transfer-out" lands can be provided as recommendations for urban planning. For example, the government can take into account the future development trend of the land-use type and the surrounding facilities and services when planning for some of the larger clusters in the identified "transfer-out" lands, so that the planning results could be more effective and reasonable. Finally, it is recommended to recognize "transfer-in" lands with the characteristics of both low urbanization probability and high ecological value, as the opposite perspective of "transfer-out" lands.

Second, the proposed framework for identifying suitable "transfer-out" lands in our study is flexible and general. The core idea of this framework is identifying land parcels of "high urban development benefit + low ecological value loss". With such a core idea, the methods and models in this framework can be replaceable. The future urbanization probabilities of land parcels can be explored using different models for urban development simulations (such as CLUE-S model) (Verburg et al. 2002; Huang, Huang, and Liu 2019). The ecosystem services values of land parcels can be evaluated comprehensively based on other methods or models (such as InVEST model) (Sharp et al. 2020). Also, the data adopted in this study, including the cadastral land-use data, driving factors data, and ECAs data can be

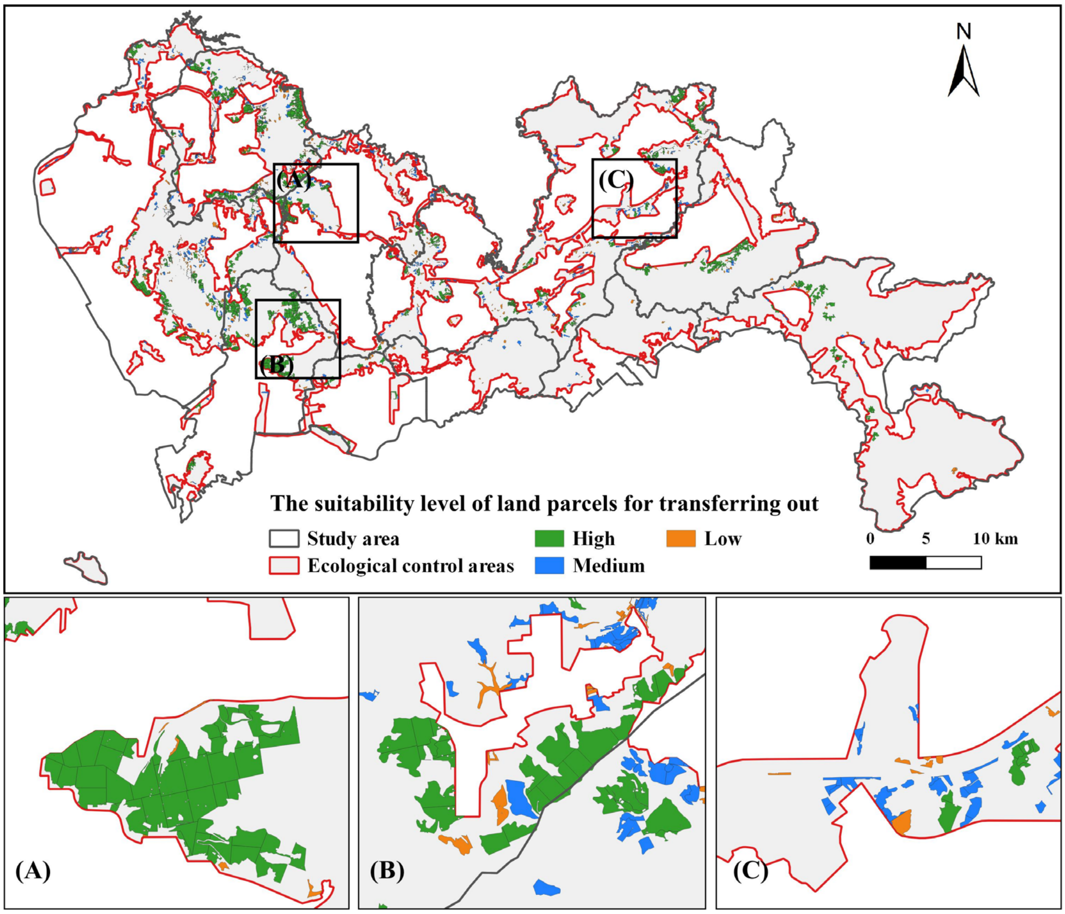


FIGURE 10 | Suitability level of identified “transfer-out” land parcels.

obtained easily for decision makers in local governments. Thus, the framework can be applied in other cities in China and other countries facing the rising conflict between ecological conservation and urban development.

This study still has some shortcomings. Assessing ecological service value is complicated and requires full consideration of carbon storage, food production, water retention, soil conservation, air regulation, and other ecological service functions (Zank et al. 2016; Zhang et al. 2017; Liu et al. 2019; Chen et al. 2020). The existing ecological indicators and models cannot illustrate the mechanism of or interaction among multiple ecological services functions, and it is still a challenge to comprehensively evaluate ecological services in the field of ecology (Layke et al. 2012; Yu, Lv, and Fu 2017). Moreover, the developmental demands of residents located within ECAs is also important (Wang 2012). More influencing factors will be introduced into our proposed framework in future work.

6 | Conclusion

The conflict between urban development and ecological protection has become increasingly severe in many countries, especially in the economic-developed regions. Since 2005, China have enacted the Ecological Control Line (ECL) policy to design the regions with some restrictions on urban development, further exacerbating land space scarcity and protecting ecological resources. How to explore the land spaces for urban development under the ECL policy has become an essential issue that must be dealt with.

This study proposes a framework for identifying “transfer-out” lands that are suitable to be transferred out of ECAs for urban development. This framework integrates the exploration of future urbanization probability and the evaluation of ecosystem services value at the land parcel scale. The identified “transfer-out” land parcels have the characteristics of both high future urbanization probabilities and low ecosystem services values. The results reasonably improved the land supply allowed for urban development to balance the relationship between urban expansion and ecological protection. The proposed framework can provide practical solutions for local government departments to adjust ECAs in China and help explore reasonable urban land management practices in different countries.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.