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Research of Urban Suitable Ecological Land Based on the Minimum Cumulative Resistance Model: A Case Study from Hanoi, Vietnam

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Abstract. Rapid urbanization process is accelerating the dramatic transformation of urban land use, creating strong economic, social and environmental impacts in Hanoi (Vietnam). Improving the quality and optimizing the model of using ecological land in urban areas is very important to solving environmental issues and sustainable urban development. Using the Hanoi capital of Vietnam, an important and typical city in the Red River Delta, as in the case of the study, we applied the Minimum cumulative resistance model (MCRM) to calculate ecological land and constructed land meet the needs of socio-economic development and ecological protection. Results showed that the suitable ecological land area is about 2.090,298km^2 (ecological land area 1.112,216km^2, ecotones land area 978,082km^2), which is 62% of the total urban area of Hanoi is mainly distributed in Bavi, Socson, Unghoa, Myduc, Chuongmy districts and Sontay town; and constructed land area is about 1.275,736km^2, which accounts for 38% mainly distributed in the city center and urban areas. Study the ecological land space and construction land of Hanoi area and compare with the current land use status through simulation of MCRM model, we propose three types of land use. For urban ecological land, there must be measures to manage and protect the ecological environment and prohibit construction activities in the area. For ecotones land between urban construction land and ecological land, it is necessary to control and limit the construction to improve the quality of the ecological environment. For construction land, there must be a policy to promote construction along with reasonable and efficient land use development to improve urban living environment.

1. Introduction

Asian developing countries are facing rapid urban population growth with an annual rate of 2.19% compared with 0.18% in Europe and 1.11% in North America [1]. In Vietnam, annual rate of urban population growth is estimated to be 3.4%, which might lead to the increase of urban population between 30% and 50% in the next 25 years [2]. The government of Vietnam plans to convert 450,000 ha of ecological land (e.g., arable land, forest, grassland, wetlands) to constructed land (e.g., residential,

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commercial, industrial land) by 2025 to accommodate the increase in its urban population, which will reach 52 million people [3]. Rapid urbanization caused by population growth is accelerating the shift from ecological land into constructed land in Vietnam, as well as in many other developing countries, especially in low and middle income countries in Asia, Africa, and Latin America facing severe urban population pressure before industrialization [4-6].

In many cities in the world, urbanization changes the land use practice, usually by reducing the natural land area [7-9]. Frenzied urbanization in Hanoi took hold in the "Doi Moi" period. Urbanization rate for the resident population in Vietnam reached 35.21% in 2017 and Hanoi reached 69.7% [10], and the spatial expansion of urban land will increasingly be the main characteristic of land use change in the future in Vietnam [11]. Urban expansion can be seen as a macro performance to reflect a micro mutual conversion of different types of land [12, 13]. The conversion of ecological land, especially arable land, to constructed land is the most significant change in the process of urbanization [14, 15]. The expansion of urban areas and intense human activity have resulted in a decrease of ecological land [16-18] and increasing the impervious cover area [19, 20]. Ecological land refers to the land-use type that mainly provides ecosystem services and usually includes low-intensity farmland, woodland, and water bodies. The dynamic change to ecological land area is the main factor that leads to changes in urban ecosystem services [21-23]. Therefore, coordinating the layout of ecological land and urban constructed land to maximize the use of constructed land without affecting ecosystem services and at the same time promoting sustainable development is a key challenge for urban planners [24].

Hanoi is a center of national politics in Vietnam, an important and typical city in the Red River Delta. It is also the center of culture, science, education, economics and international trade. Hanoi has become one of the most populated cities in the world after expanding significantly in 2008; it is characterized by rapid urbanization and a changing spatial structure of ecological land. According to the Hanoi capital master plan to 2030 and vision to 2050, Hanoi is now focusing on expanding construction land as a driving force for the urban development process, while there is not much research on ecological land needed for urban sustainable development strategy, which components of ecological land should be reserved to protect and maintain the ecological environment for the capital. Defining the area and extent of ecological land is the basis for overall urban planning and land use planning, and the concept of ecological land has been proposed [25]. In this research we use the concept of urban ecological land as defined by Li et al. (2009): urban ecological land is aimed at improving the quality of life of people in cities, protecting important ecosystems and habitats, maintaining and improving the natural and urban artificial ecological unit, and stabilizing the urban ecosystem services at a certain level. Suitable ecological land is the best suitable land area for ecosystem protection based on balancing the value of ecosystem protection and economic development in cities.

Using the (MCRM) model combined with ecological and social factors in urban areas, we have built a resistance plane to expand the ecological land and constructed land to calculate the necessary land area to expand urban development with urban ecosystem protection. By examining the change in spatial and functional of ecological land, combined with the current status of the area; we make suggestions to maintain a sustainable ecological environment in the process of building and expanding Hanoi in the future. This research provides an important part in regulating and expanding construction land in combination with protecting ecological land; coordinate the expansion of urban land with ecological land conservation and urban ecosystem services, improving the quality of life for urban residents.

2. Study area and methods

2.1. Study area

Hanoi, Vietnam, is located in the northwest of the center of the Red river Delta and the intersection of Red river and Duong River, with coordinates from 20º53' to 21º23' North latitude and 105º44' to 106º02' East longitude (Figure 1). After the expansion of administrative boundaries in August 2008, Hanoi area is 3358,9km^2, including 12 districts, 1 provincial town and 17 rural districts and becomes the largest cities of the natural area and ranks 2nd in urban area after Ho Chi Minh city. Hanoi mainly comprises two different topographical features: the delta and the Middle region of Bacbo. Most of the deltaic land lies on both sides of the Red river and its tributaries, while the Middle region extends towards the Delta. Hanoi lies on the

plain and is far from the sea. It belongs to a tropical region and is greatly affected by the monsoon. The climate in Hanoi is very comfortable and where four common seasons are discernible; January is the coldest month and the monthly mean temperature is 16,5°C, July is the hottest month and the monthly mean temperature is 29,5°C, annual average temperature of 23°C, sunshine of 1562h per year and annual precipitation of 1.900mm. By the end of 2015, green land area in the total land built-up area of Hanoi center reached only 1.92%, the average area of green land reached 2.08m^2/person [26]. Currently in urban areas, urban land use structure is seriously imbalanced, green space and social infrastructure are lower than national standards. Urban planning and management did not seriously consider the long-term development of the city and the tremendous changes in the ecological environment. The current status of the green space landscape in Hanoi is single, and the spatial distribution of patches is uneven. The fragmentation of the green space has a large impact on the environmental function of the green space. The current lack of link corridors and networks between green patches has affected the material and the continuous flow of energy.

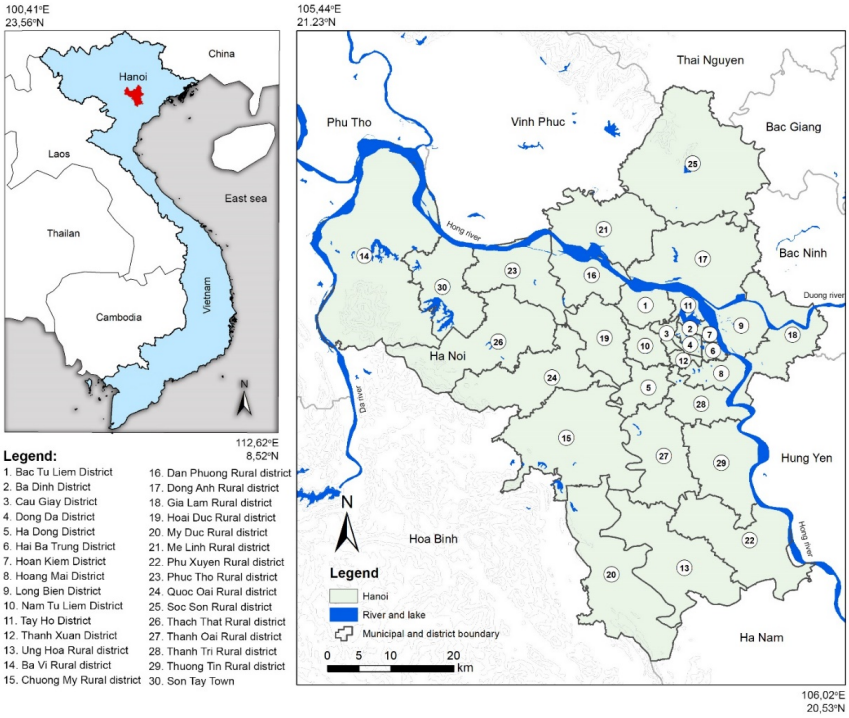


Figure 1. Location of the study area.

2.2. Data collection

We used 30m resolution Landsat 8 OLI/TIRS data by USGS from June 04, 2017 (path/row 127/45) as the remote sensing imagery for this study, the selected image has less than 10% cloud cover, which is representative of the season; and Digital Elevation Model (DEM) used 30m resolution ASTER Global DEM V2 data by LP DAAC from 2009. We selected the area of interest from the 2008 Hanoi capital construction Master Plan land status map (scale 1:25.000) and then applied supervised classification of the remote sensing image followed by precision calculations and fine-tuning of the local classification.

2.3. Methods

2.3.1. Principle of the Minimum cumulative resistance model. With respect to ecological processes, a heterogeneous landscape can be divided into a "source" or "sink" landscape, of which the source landscape consists of those processes that can promote the development of landscape types and the sink landscape consists of those processes that can prevent or delay the development of landscape types. Although source and sink landscapes have opposite qualities, a source landscape in one process may become a sink

landscape in another. The main purpose of proposing the Source and Sink Landscape Theory [27] is to explore how the dynamic balance of landscape types affects ecological processes, which in turn leads to the identification of a suitable spatial pattern in every region. The transformation between source and sink occurs as a mutual conversion or as a competitive process for the control and coverage of space; this competitive process is achieved by overcoming various forces of resistance, which are then integrated to reflect the resistance surface or "plane".

The MCRM essentially reflects the degree of resistance in landscape development. The cost distance in the model differs from the actual distance and instead emphasizes the relative spatial relationship between points. This relative relationship is based on calculating the drag coefficient when the target unit passes through different landscape units. Based on the value of the minimum cumulative resistance when a target unit passes through a specific unit, we can determine the "connectivity" and "similarity" between the two units and usually the "source patch" that is the initiator of the ecological process. To determine the minimum cumulative resistance value *MCR*, we use the following formula as modified by Yu [28]:

$$MCR = f_{min} \sum_{j=n}^{i=m} (D_{ij} \times R_i)$$

Where f is a function of the positive correlation that reflects the relation of the least resistance for any point in space to the distance from any point to any source and the characteristics of the landscape base surface;

min denotes the minimum value of cumulative resistance produced in different processes of landscape unit *i* transforming into a different source unit *j*;

D_{ij} is the spatial distance between landscape unit *i* and source unit *j*;

Ri denotes the resistance coefficient that exists in transition from landscape unit *i* to source unit *j*

In urban areas, there are two processes that expand the ecological land to protect the urban environment and the process of expanding construction land for urban development (Figure 2). In Figure 2, P and L denote the cumulative resistance curve of the expansion of constructed land and ecological land, respectively, and C is the balance line between the two processes. Between AC, the *MCR* of ecological land is greater than the *MCR* of constructed land, which facilitates expansion of constructed land and makes this area suitable for development. Conversely, between CB, the area is suitable as ecological land.

Based on the resistance process of the two land sources, the modeling formula is:

$$MCR = MCR_{ecolo} - MCR_{const}$$

Where MCR_{ecolo} and MCR_{const} denote the *MCR* of expansion of ecological land and constructed land, respectively.

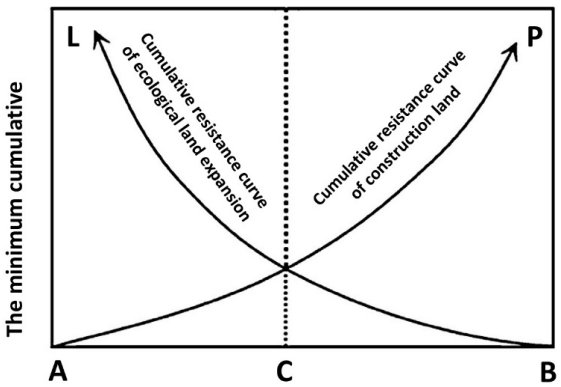


Figure 2. Balance of constructed land and suitable ecological land based on the minimum cumulative resistance model (modified from Liu [29]).

A land unit in the urban setting where $\Delta MCR < 0$ signifies that the resistance in development of ecological land is less than that in expansion of constructed land, indicating that the protection of ecological land is easier, so this land unit should be classified as suitable ecological land. A land unit where $\Delta MCR >$

0 signifies that the resistance in development of ecological land is greater than that in expansion of constructed land. Constructed land is easier to enlarge, so this land unit should be classified as suitable constructed land. When the land unit $\Delta MCR = 0$, the land unit can be treated as an interlaced zone that is suitable for both construction and ecological land. The model can be used in a cost–distance module in Esri's geographical information system ArcGIS.

There are a number of model assumptions:

1) This paper divides the use of urban land into two categories: ecological land, which is land that is most suitable for ecological protection, and non-ecological land, which is land that is most suitable for construction.

2) For maximum ecological protection, ecological land requires expansion. To achieve maximum economic and social benefits, non-ecological land requires extensive expansion. These two processes interact with each other, with the challenge of finding a balance between suitable ecological land and non-ecological land.

3) The expansion of ecological land can be promoted by important ecological factors of land (e.g., wetlands, rivers, green space), thus limiting the expansion of non-ecological land. In other words, the same land can be provided to drivers or constraints according to different processes.

4) The efficiency of the land is determined by whether promotion or restraint is identified by the MCR value under different sources of expansion and resistance.

2.3.2. Model variables.

(1) Source selection

Sources are landscape types that promote the development of ecological processes. Sources may include natural areas, areas of special protection or areas of existing habitats that reflect different types of habitats. During the MCR calculation, the input of the source grid can be a patch or a combination of patches, and the source grid can be connected or unconnected in space. In this study, the expansion of construction land was taken from the 2008 land use classification map (Figure 3. a). Extensive sources of ecological land include land considered to have rich biodiversity and ecosystem services, wetlands, drinking water, lakes and large rivers, and greenbelt zones areas. In Hanoi this expansion source includes the main stem rivers (Red river, Da river and Duong river) and the branch rivers (Day river, Nhue river, Tich river, Cau river, Calo river, Tolich river,…); important wetlands, the confluence of the main stem rivers and lakes (Vantri wetland, Dongquan lake, West lake, Suoihai lake, Dongmo lake, Tuylai lake,…); important mountains, natural landscape reserves, and important urban green space (Socson mountain, Bavi mountain, Huongson mountain, non–commercial forest and Urban park) (Figure 3. b).

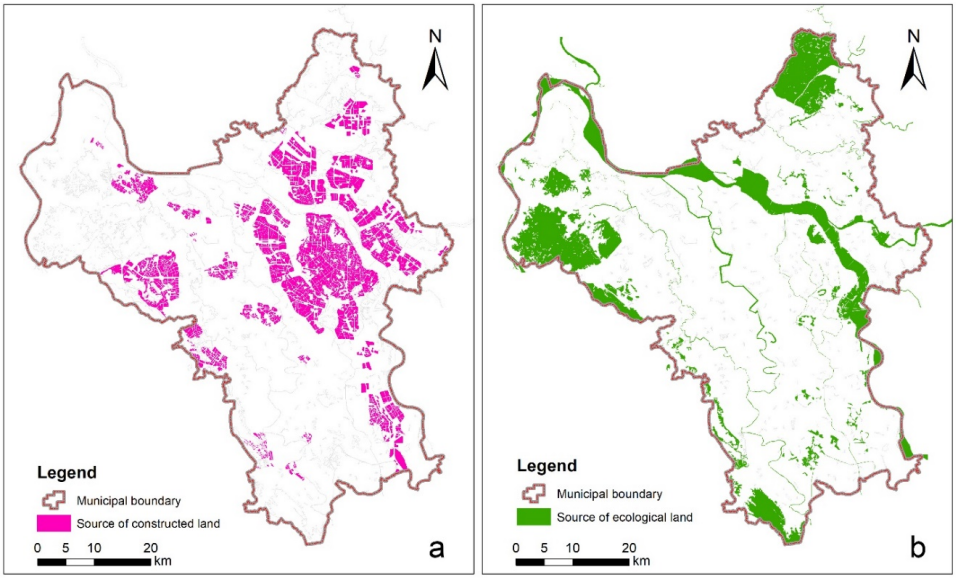


Figure 3. Source of (a) constructed land and (b) ecological land in the Hanoi area.

(2) The setting of the resistance plane

Land use in an urban environment can be considered as competition control, and the process of covering space must be done by overcoming resistance. The spatial heterogeneity of the land identifies several land units with different resistivity coefficients to form the resistance plane of the space. Resistant plane includes the location and orientation elements of the landscape elements and the resistance factors of the horizontal elements that extend the land. The resistivity factor is influenced by environmental factors and shows several levels of some plots that become a specific land type.

In this study, the selection of resistant plane mainly originates from surface markers and originates from elevation, slope, soil geology, distance between rivers and reservoirs and other sources, and other environmental factors. The resistance of different elements of the land depends on the type of land and is affected by the relative resistance, not the absolute value. We used 1 – 5 to represent the different levels of resistance, with 1 being lowest and 5 being highest, which is a subjective determination and not calculated by the MCRM [29]. For the selection of suitable factors of the resistance plane for different sources, we considered six aspects of the geography of Hanoi: landscape type, soil type, altitude, vegetation coverage, distance from water bodies, and distance from main roads (Table 1). From these, we have chosen the factors that may constitute resistance to construction land and ecological land.

The Landscape type (Figure 4. a) can reflect land use, so you can more clearly indicate the likelihood that one type of landscape type will be converted to another. For example, water bodies are an important component of ecological land with a large value in ecosystem services [30] and should be protected, not over-developed. Therefore, these components are less resistant to ecological land expansions and are more resistant to the expansion process of the constructed land. We have divided landscape types into five categories: farmland, water, forests, urban green space and land construction land based on land classification.

Table 1. The value system for resistance factors to constructed land and ecological land.

Levels of resistance	Constructed land		1	2	3	4	5	Weights
	Ecological land		5	4	3	2	1	
Resistance factors			**Resistance level classification**					
Ecological	1. Landscape type		Construction land	Urban green space	Farmland	Forest	Water	0.330
	2. Altitude (m)		<5	5-10	10-25	25-50	>50	0.169
	3. Soil type		Urban land	Fluvisols	Ferralsols	Gleysols and Histosols	Wetland	0.220
	4. NDVI		0.025-0.2	0.2-0.3	0.3-0.42	>0.42	-0.299-0.025	0.156
			No vegetation	Barren rooks, sand	Agricultural field	Dense vegetation	Water body	
Social	5. Distance from water bodies (m)		>200	150-200	100-150	50-100	0-50	0.063
	6. Distance from main roads (m)	Express way	>1000	600-1000	300-600	150-300	0-150	0.061
		National road						
		Arterial road	>500	300-500	200-300	100-200	0-100	

Altitude (Figure 4. b) used 30m resolution ASTER Global DEM V2 data by LP DAAC from 2009 for this study. Altitude categorized these into five groups: <5m, 5–10m, 10–25m, 25–50m, and >50m.

Soil type (Figure 4. c) reflects the ease of building in a region with one land type. For soil type we used the Hanoi Soil map (Vietnam Environment Administration) [31].

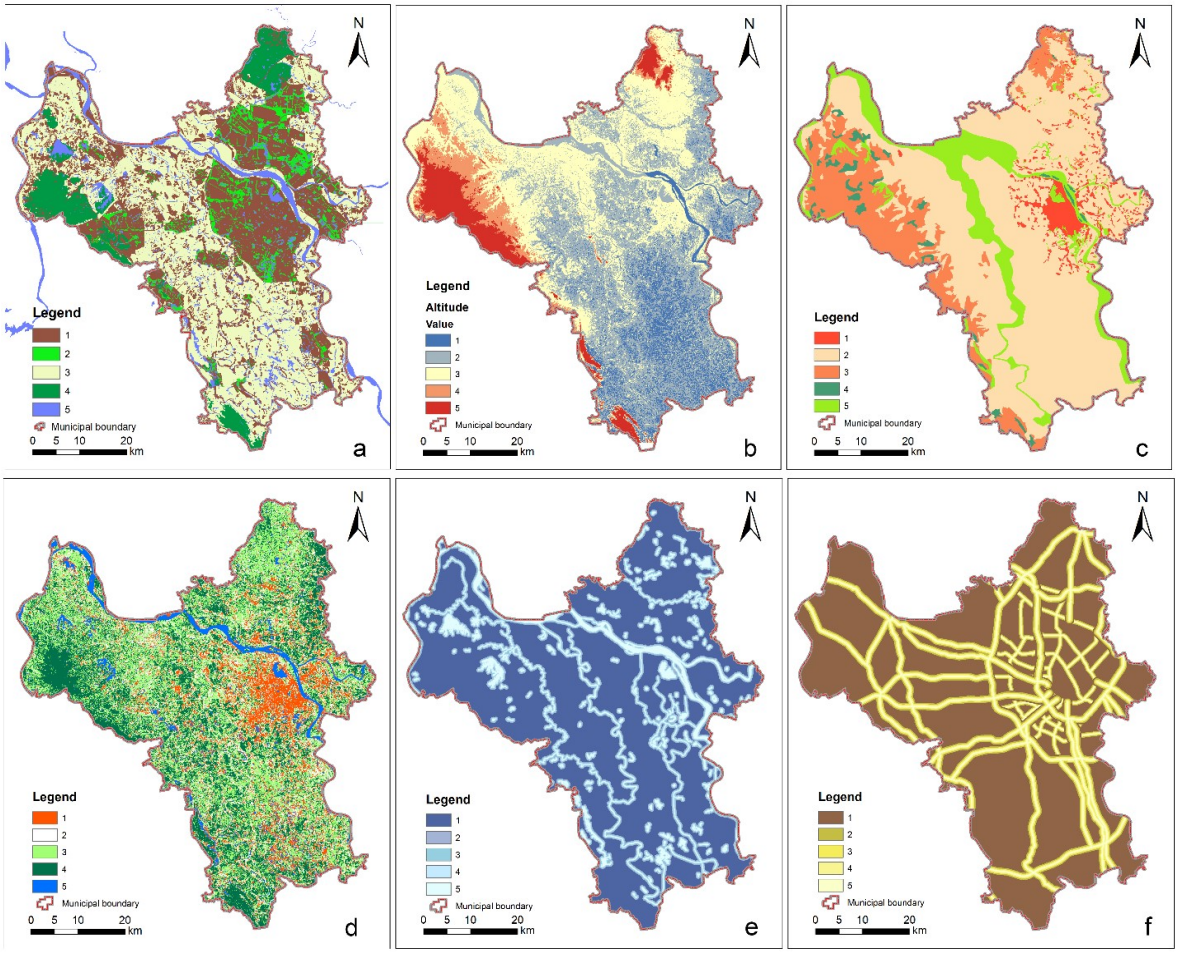


Figure 4. Each resistance factor spatial distribution and classification raster.
(a) Landscape type; (b) Altitude; (c) Soil type; (d) NDVI, (e) Distance from water bodies; (f) Distance from main roads

Vegetation coverage (Figure 4. d) denotes the density of local vegetation and reflects the important ecological effects of vegetation on the urban ecological system. High density vegetation coverage can provide numerous ecosystem functions and has a low resistance value to ecological land, so it is easy to protect. Vegetation coverage is measured in remote sensing imagery by the normalized difference vegetation index (NDVI). NDVI is calculated as a ratio between the red (RED) and near infrared (NIR) values: *NDVI = (NID–RED)/(NID+RED)* [32]. In Landsat 8, *NDVI = (Band 5–Band 4)/(Band5+Band 4),* here band 4=RED and band 5=NIR. NDVI value ranges between -1 to +1. A Higher value of NDVI infers the presence of healthy vegetation in the area while its lower value is the indicator of sparse vegetation.

For distance from water bodies (Figure 4. e), we took into consideration the characteristics of the rivers and lakes in Hanoi and categorized these into five groups: 0–50m, 50–100m, 100–150m, 150–200m, and 200m or more. And for distance from main roads (Figure 4. f), we categorized these into three groups: Express way, National road, Arterial road.

Determination of the resistance weights, for the range of resistance weights and the range of values, foreign scholars have conducted relatively more research. Knaapen believe that the determination of the resistance weights is a reasonable basis based on the comprehensive investigation of species behavior characteristics. Relative values to reflect differences between different resistance factors [33]. This paper is

obtained through the Delphi method and the previous research experience [34]. The resistance weights of the same factor corresponding to the ecological source and the construction source are opposite. The weights of the six evaluation factors are based on the establishment of the Analytic hierarchy process (AHP) and the judgment matrix, which are *Landscape type 0.330, Altitude 0.169, Soil type 0.220, NDVI 0.156, Distance from water bodies 0.063, Distance from main roads 0.061; CI = 0.048, CR = 0.036* (Table 1).

According to the resistance weights of the above ecological protection land expansion resistance base, according to the factor weight, use ArcGIS for weighted superposition, the specific steps are: select Raster Calculator under the Spatial Analyst command, use the calculator to edit the weighting formula: *"Landscape type"*0.330 + "Altitude"*0.169 + "Soil type"*0.220 + "NDVI" * 0.156 + "Distance from water bodies" *0.063 + "Distance from main roads"*0.061*, get the layered result layer, which is the expansion resistance base of the ecological source of this MCR study, such as (Figure 5) shows the expansion resistance base of ecological and constructed sources in Hanoi.

3. Results and Discussion

Expanding urban land is a process that must be controlled competitively and needs to be overcome the resistance of the landscape. For example, ecological land achieves expansion by protecting and expanding natural ecosystems, while the constructed land must overcome its ability to resist different types of ecological land to achieve openness. The resistance plane of ecological land or constructed land reflects the minimum cumulative resistance value for each land unit transforming into its source ecological land or constructed land. As the resistance value increases, the likelihood of successful transformation from original land into its source land decreases; in contrast, a smaller resistance value increases the likelihood of successful transformation.

After calculating and modeling, the resistance value of ecological land in Hanoi City is between 0 and 14.661,5 (Figure 6. b), and the resistance value of constructed are between 0 and 49.543,5 (Figure 6. a). The land with high values of resistance, which indicate an advanced level of constructed development, is mainly distributed in the Hanoi center. The area with a greater resistance value is mainly aroun the river (Red river, Da river and Duong river) and the branch rivers (Day river, Nhue river), wetlands, mountains (Socson mountain, Bavi mountain, Huongson mountain) and natural landscape reserves. The total area of ecological land in Hanoi is 1.112,216km^2, ecotones land is 978,082km^2, constructed land is 1.275,736km^2, which accounts for 33%, 29%, 38% of the total land area of the city (Table 2). Suitable ecological land is mainly located in Bavi, Socson, Unghoa, Myduc, Chuongmy rural districts and Sontay town (Figure 7) (Figure 8).

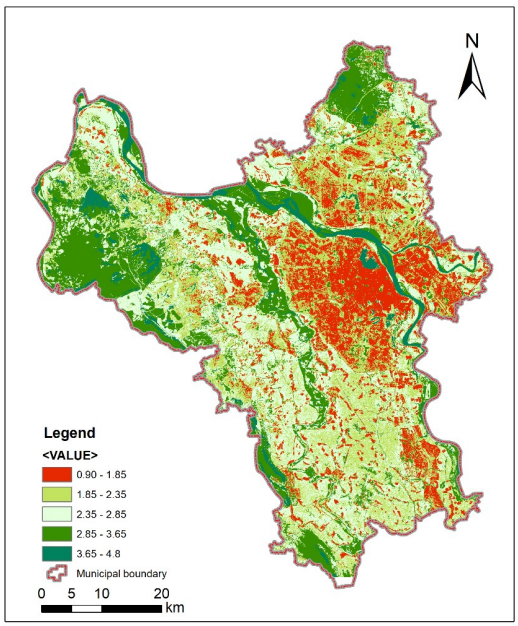


Figure 5. The expansion resistance base of ecological and constructed sources.

3.1. Coordinate to protect ecological land and construction land

In urban development, at the same time, the protection of ecological land and the expansion of constructed land are coexistent processes. Ecological land is a type of land use that mainly provides urban ecosystem services and often includes agricultural land, forests and water areas, changes in ecological land are the main reasons leading to change in ecosystem services in urban areas. Constructed land plays an important role in urban development. In the urban planning process, the introduction of an appropriate ecological soil concept helps to calculate the area and spatial extent of ecological land to improve and improve the environmental quality for the city; helping urban planners solve the problem between urban development and sustainable ecological environment protection.

Table 2. Proportion (%) of constructed land, ecological land, and ecotone land of the Hanoi urban area.

Type land (Figure 8)	**Area (m^2)**	**Proportion (%)**	**Suitability zoning** (Figure 7)	**Pixel value range**	**Area (m^2)**	**Proportion (%)**
Ecological land	1,112,216,000	33	Prohibited development zone	-49,554 - -5,000	1,112,216,000	33
Ecotone land	978,082,200	29	Restricted development zone	-5,000 - 0	978,082,200	29
Constructed land	1,257,736,000	38	Key development zone	0 - 3000	858,933,000	26
			Optimization development zone	3,000 - 10,100	398,803,500	12

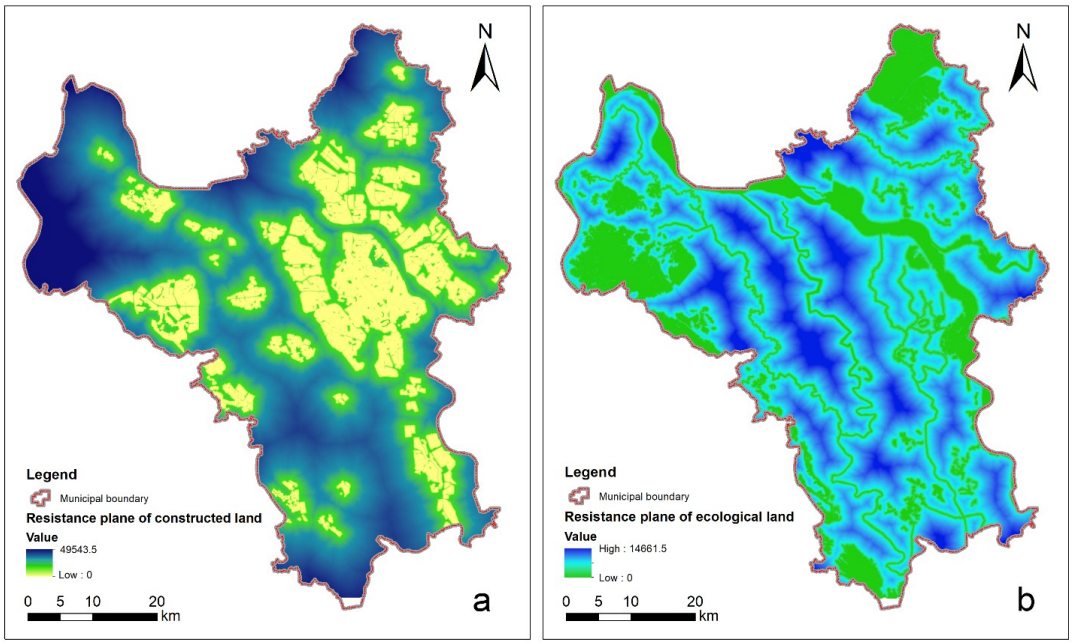


Figure 6. Resistance plane of (a) constructed land and (b) ecological land in the Hanoi urban area.

3.2. Strategies for protection of suitable ecological land

Research results show that the value of suitable ecological land ranges from -49.554 to-5000 (Figure 7) and the above value range includes mountains, lakes, rivers, natural landscape protected areas. The Red River, Duong river, Dongquan lake, Suoihai lake, Dongmo lake, Tuylai lake play an important role in maintaining regional ecological balance and the conservation of biodiversity. Other low mountain or hilly areas include Socson mountain, Huongson and Bavi mountain, which have important ecosystem services and are also important to Hanoi. Farmland plays an important role in food security, maintaining biodiversity, and habitat for plants and animals. In addition to protecting the existing ecological areas, we must also build ecological

buffer belts around urban areas and residential areas, step by step improve the urban ecological environment. Research and establishment of a protected green corridor along the Red river to bring benefits to the protection ecological environment. A prohibition on development of areas in and around important ecological landforms, such as Suoihai lake, Dongmo lake, Dongquan lake, Tuylai lake, mountains (Socson mountain, Bavi mountain, Huongson mountain), and other areas. The establishment of country forest parks combined with the existing natural resources would protect the environment and improve the quality of life of urban residents and other existing open spaces could improve the deficiencies of public green space in the urban core area. Building ecological networks by combining historical and cultural landscape protection areas could achieve environmental protection, ecological stability, and enhance the value of urban open space.

Land with a suitable ecological land value ranging from -5000 to 0 (Figure 7) value range includes the branch rivers (Day river, Nhue river, Tich river, Calo river, Cau river, Cong river), regions wetlands (Vantri wetland), around the edge of West Lake and around the city center and urban areas. These areas serve as a buffer between construction land and ecological land, maintaining the quality of urban ecological environment as well as nature conservation areas. Therefore, the construction of green corridors along rivers and roads does not only effectively connect natural resources but also improve the ecological environment in urban areas and helping to control urban expansion. Research and establishment of buffer greenbelts on both sides of the roads and along the river, coupled with strengthening the connection of ecological space functions throughout the region can reduce the urban heat island effect, control pollution and flooding in urban areas. Removing the buildings and structures in the urban areas with important ecosystem service, guiding the development of urban space, and avoiding disordered growth, loss of arable land, and low land-use efficiency will help to restrain construction space expansion, especially at the city's edge.

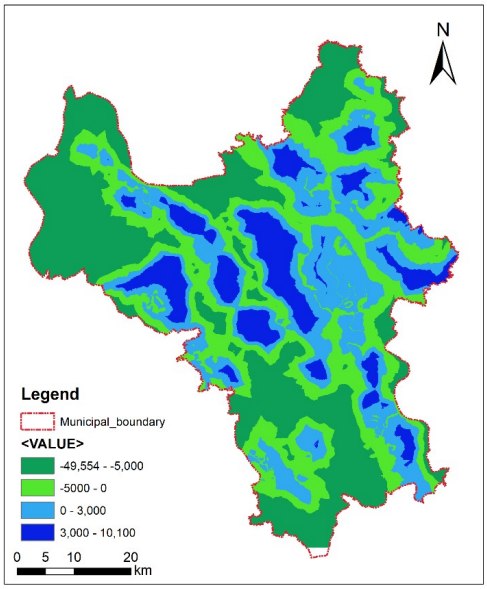


Figure 7. Distribution of suitable ecological land in the Hanoi urban area.
(The colors from green to blue represent a suitable ability from ecological land to constructed land. Colors with values below 0 are suitable for ecological land, while colors with values above 0 are suitable for construction land)

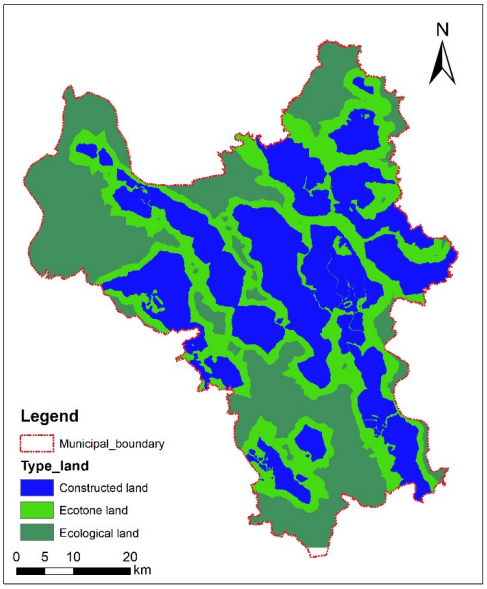


Figure 8. Construction land, ecological land, and ecotones in the Hanoi urban area.

Land with a value above 0 (Figure 7) is suitable as constructed land; this mainly includes Hanoi City center, Eco-town and Satellite city and. Characteristics of these areas are land resources that have been developed and limited in space expansion. Therefore, we need to evaluate the effectiveness of land use in

the region to improve the efficiency of land use by restructuring the land; effective land management and land use will help prevent unnecessary expansion; coupled with control and isolation from pollution sources that endanger the area. On the other hand, restoring constructed land to ecological land has a greater resistance and therefore a lower possibility. Thus, we should strengthen the protection of existing ecological land and avoid the expansion of constructed land that may make ecological land unrecoverable.

In order to maintain urban ecological land and improve the ecosystem services it provides, we propose some ideas as follows: (a) strengthening the ecological functions of wetlands, green land in urban areas, gray land, urban drainage systemsand ecological corridors at the ecosystem level; (b) Increasing the diversity of wetland plants to track seasonal changes in natural wetlands; (c) Improve and rehabilitate wetland ecological functions to revitalize the water ecosystems of urban areas; (d) enhance natural water absorbency for green space and the ability to retain natural water of lakes and wetland areas.

4. Conclusion

In this paper, we used the MCRM to select landscape type, soil type, altitude, vegetation coverage, distance from water bodies, and distance from main roads suitable to the ecological and social conditions and attributes of Hanoi. With the above research results, we have developed a resistance assessment system to identify suitable ecological lands to maintain urban ecosystems, control future urban development and urban expansion, step by step improve the quality of living environment of urban residents.

Research results showed that suitable ecological land in Hanoi accounts for 62%, and constructed land accounts for 38% of the total land area of the city. The process of urbanization in the capital of Hanoi is happening rapidly, the determination of land demand for building urban development in parallel with protecting ecological land is extremely important. For ecological land, there must be measures to manage and protect the ecological environment and prohibit construction activities in the area. For ecotones land between urban construction land and ecological land, need to control and limit the construction and improve quality of ecological environment, ensure connection of landscape and urban spatial integrity. For suitable construction land, there must be a policy to promote construction along with reasonable and efficient land use development to improve urban living environment.

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