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# Impact of Cropland Reclamation on Ecological Security in the Yangtze River Economic Belt, China

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**Abstract:** Ecological security is important both for maintaining the function of an ecosystem and for providing ecosystem services to the human wellbeing. The impact of land use change/cover on ecological security has attracted considerable attention, whereas the role of cropland reclamation remains unclear. The indirect loss of ecological land that occurs upon the request of cropland requisition-compensation policies offer further changes to ecological security. In order to ascertain the impact of cropland reclamation on ecological security, in this study three scenarios are established, addressing cropland returning to ecological lands without a slope limitation, with a slope <25°, and with a reclaimed cropland slope ≥25°. This study was conducted in the Yangtze River economic belt (YREB) due to its important contribution to ecological security in China. Land uses in different scenarios in 2030 are projected using the land use simulation model LANDSCAPE. Accordingly, ecological security in each scenario was evaluated using the contribution–vigour–organization–resilience framework, comprising the variables carbon storage, water purification, water yield, habitat quality, net primary productivity, mean patch area, Shannon's diversity index, largest patch index and contagion, as well as the normalized difference vegetation index. The results indicate that about 62% of YREB land is projected to remain stable in terms of ecological security, while about 21% will deteriorate and 17% will improve between 2015–2030. Land where ecological security is projected to improve is concentrated in areas where broad and connected croplands are distributed. The fact that a higher proportion of areas will deteriorate than improve suggests that the negative impact of cropland change on ecological security should not be ignored. Comparing different scenarios, croplands returning to ecological lands pose a particularly significant impact on ecological security, particularly in the upper reaches of the YREB, where steep croplands are concentrated.

**Keywords:** ecological security; cropland reclamation; Yangtze River economic belt; landscape model; scenario analysis



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## 1. Introduction

Ecological security refers to the state of a (semi-)natural ecosystem that can sustain its organization and function and has the capability to provide sustainable ecosystem services, as proposed by the International Institute for Applied Systems Analysis (1989). Today, ecological security is under unprecedented pressure due to rapid urbanization and frequent interference from human activities. Previous research has debated the impacts on ecological security posed by natural disasters [1], urbanization [2–4] and land use change/cover (LUCC) [5].

The evaluation of ecological security dates back to the 1980s, when the concept of ecosystem health was first proposed [6,7]. A framework of vigour–organization–resilience (VOR) was developed to evaluate ecosystem health, in line with the definition of health in stress ecology as "system organization, resilience and vigour, as well as the absence of signs of ecosystem distress" [6,8]. The VOR framework has been extended to evaluate ecological security in order to highlight the increasingly close interaction of human and ecosystem [9], among which a contribution–vigour–organization–resilience (CVOR) framework was proposed to reflect the services or goods that an ecosystem provides to humans (i.e., ecosystem services) in addition ecosystem health, understood as its ability to maintain its own function and structure [10–13]. Other approaches have also been developed to assess ecosystem health, for example, indicator assessments [14,15], pressure–state–response (PSR) and its extended framework driving–pressure–state–influence–response (DPSIR) [16] and footprint assessments [17]. The CVOR framework is superior to the other approaches as it reflects ecological integrity and natural ecosystem quality at a grid level and is thus applied in this study to evaluate ecological security.

Despite the fact that the impact of LUCC on ecological security has been widely documented, the role of cropland reclamation is often ignored. With the aim of ensuring food security, cropland reclamation with the same quantity and quality is requested when croplands are lost due to urbanization in China. Consequently, ecological lands (referring to land use types that provide valuable ecosystem services such as forests, grasslands and water bodies) are indirectly occupied by cropland reclamation. The impact of ecological land loss during cropland reclamation has been revealed in terms of ecosystem services such as food production [18], carbon storage [19], habitat quality [20], water yield [21] and water purification [22]. It has even been argued that the indirect impact on ecosystem services from ecological land loss due to cropland reclamation can be higher than that caused directly by urban expansion. As [20] has documented, cropland reclamation under a strict cropland protection policy can indirectly result in the loss of natural habitats, a loss that is much greater than the direct loss caused by urban expansion. Moreover, it has been estimated that the loss of carbon storage caused by cropland reclamation between 2000 and 2010 was 1.12 times more than that resulting from urban expansion in the same period [23]. This implies that the indirect influence of cropland reclamation on ecological security should not be ignored, as cropland reclamation is still taking place [24]. Nevertheless, the indirect impact of cropland reclamation on ecological security remains unclear.

In response, this study assesses ecological security by focusing on the impact of indirect ecological land loss due to cropland reclamation. The Yangtze River economic belt (YREB) was chosen as the study area because of its dense population, large gross domestic product (GDP) contribution and importance with regard to ecosystem service provision in China. The land use patterns of the YREB in 2030 are projected using the LANDSCAPE land use simulation model [25]. Subsequently, ecological security is evaluated by applying the CVOR framework. As a consequence, the impact of the indirect loss of ecological land due to cropland reclamation can be revealed.

## 2. Methodology

### 2.1. Study Area

The Yangtze River is the largest river in China and the third largest in the world. Regions along the Yangtze River have been collectively described as "the Granary of China" for thousands of years, because the river not only provides abundant water resources but also fosters fertile soil for agricultural production. The YREB covers 11 provinces and municipalities across China from west to east, together representing 21% of the whole country. The upper reaches (i.e., in the west) of the YREB consist of the provinces of Yunnan, Sichuan and Guizhou and the municipality of Chongqing; the middle reaches comprise the provinces of Hunan and Hubei; and the lower reaches (i.e., in the east) consist of the provinces of Jiangxi, Jiangsu, Zhejiang and Anhui, and the municipality of Shanghai (Figure 1).

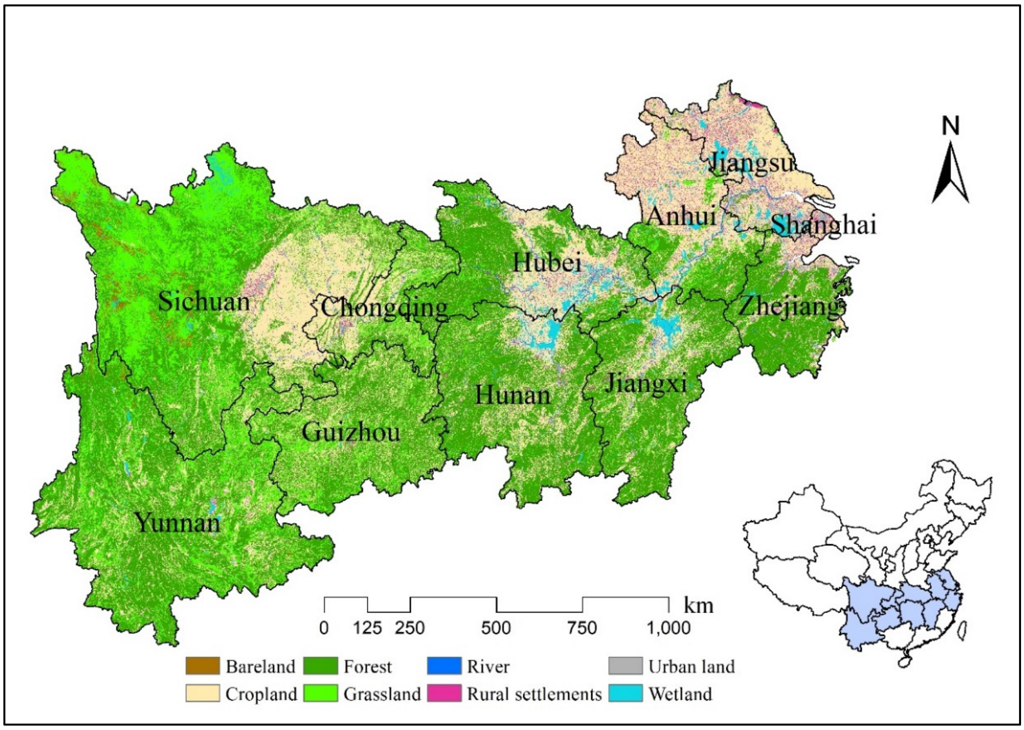


**Figure 1.** Illustration of administrative boundaries and land uses of the YREB (2015).

The YREB includes 40% of the country's population and contributes 40% of its GDP. In addition, it is an important ecosystem service supplier both locally and nationally. In general, the upper reaches are rich in natural resources and are ecologically sensitive, with a population facing significant levels of poverty, while the lower reaches are more developed and face greater stress due to the comparatively high population density. Moreover, the terrain of the YREB tends to be flatter following an upper–lower reaches gradient; in other words, areas with a slope $\geq 25°$ are concentrated in the upper reaches of the YREB.

The development of the YREB has encountered various challenges in recent years, such as food security, ecosystem degradation, water pollution, biodiversity loss, unbalanced regional development and the transformation and upgrading of industrial sectors. Through the implementation of the *Outline for the Development Plan of the YREB* (2016), the YREB's development has come to be regarded as one of three national development strategies in China. By developing the YREB, the aim is to bring high-quality development as a pilot of ecological rehabilitation in China. In other words, this outline calls for green development, rather than over-development characterized by the pursuit of economic development at the cost of natural resources.

### 2.2. Research Framework

The research framework in Figure 2 illustrates this study's analysis of the impact of cropland reclamation on ecological security in the YREB from 2015 to 2030, which comprises three parts: (1) scenarios establishment; (2) land use simulations; and (3) ecological security evaluations. Given that the *Outline for the Development Plan of the YREB* (2016) has been implemented since 2016 and the year 2030 acts as an important planning target year, changes in ecological security during this period (2015–2030) will be analyzed.

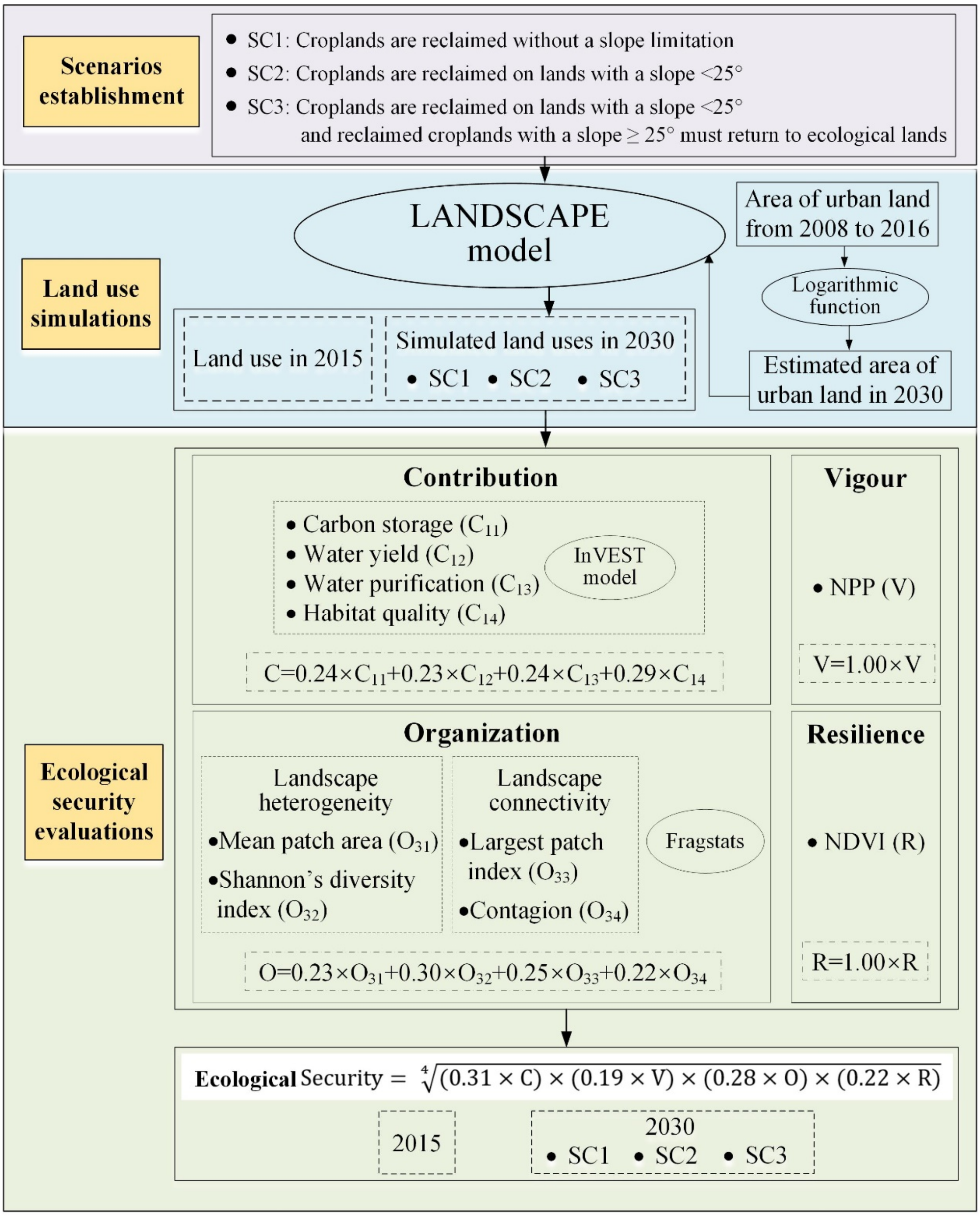


**Figure 2.** Flowchart of the research.

One of the most important ecological restoration projects in the world, Grain for Green, has been implemented in China since 1998. This policy requests that croplands with a slope ≥25° be returned to forest, because these lands are ecologically sensitive and are not suitable for cultivation. Accordingly, three scenarios of cropland reclamation are established in this study: (1) croplands are reclaimed without a slope limitation ("SC1" hereafter); (2) croplands are reclaimed only on ecological lands <25° ("SC2" hereafter); and (3) croplands are reclaimed on ecological lands <25°, while reclaimed croplands ≥25° are returned to ecological lands ("SC3" hereafter).

For the land use simulations, the land use simulation model LANDSCAPE was applied [25]. As cropland reclamation is requested when cropland is occupied by urban expansion, the quantity of cropland reclamation should be no less than that of the occupied cropland. Accordingly, the quantity of cropland reclamation depends on the demand for urban land in 2030 and thus needs to be the same or higher than the change in the area of urban land from 2015 to 2030. The demand for urban land can be predicted with a logarithmic function based on the area of urban land from 2008 to 2016 (see Appendix A, Table A1). An increase in urban land from 2015 to 2030 is possible for any type of land use, but it has been requested that occupied croplands be reclaimed from ecological lands, for example, forests, wetlands and grasslands. In addition, the area of river should remain unchanged in accordance with Yangtze River protection policies (see Appendix A, Table A2).

Based on the simulated land use maps of the YREB in 2030, the ecological security of different scenarios can be revealed by applying the CVOR framework, whereby contribution refers to the ecosystem services provided to humans [11,13]; vigour reflects activity, metabolism or primary productivity; organization represents heterogeneity and connectivity between ecosystem components; and resilience (also described as ecosystem elasticity) refers to the capability to rebound from perturbations [6,8]. The indicators of VOR applied in this study follow [3], as widely used in evaluations of ecosystem health. Specifically, this study develops the CVOR framework as follows: (1) contribution is reflected by ecosystem services, including carbon storage and sequestration ("carbon storage" hereafter), water yield, water purification and habitat quality. All of these ecosystem services are evaluated by the InVEST model and are selected based on their importance in contributing to ecological security in the YREB, as referenced by empirical studies [11,26,27]. (2) Vigour is reflected by net primary productivity (NPP). (3) Organization is assessed by landscape heterogeneity (mean patch area and Shannon's diversity index) and landscape connectivity (largest patch index and contagion) is assessed using FRAGSTATS software. (4) Resilience is reflected by the normalized difference vegetation index (NDVI) and is assessed by applying a modified formula (Formula (1)).

$$RC_i = \frac{NDVI_i}{NDVI\_mean_i} \times RC_j \quad (1)$$

where $RC_i$ indicates the resilience coefficient of the raster $i$; $NDVI_i$ refers to the NDVI value of rater $i$; $NDVI\_mean_i$ reflects the mean value of the NDVI of land use type $j$, to which the raster belongs; and $RC_j$ indicates the resilience coefficients of land use type $j$. The resilience coefficients of each land use type are given by [11,28,29] (see Appendix A, Table A3).

All the 10 indicators of the CVOR framework are normalized by applying Formulas (2) and (3), among which water purification is normalized using Formula (2) as a negative indicator (a low value indicates a positive contribution to ecological security). Other indicators are positive indicators and are normalized by following Formula (3).

$$x^* = \frac{x_{max} - x}{x_{max} - x_{min}} \quad (2)$$

$$x^* = \frac{x - x_{min}}{x_{max} - x_{min}} \quad (3)$$

where $x^*$ indicates the normalized value of each indicator of the CVOR framework; $x$ refers to the value of a raster; $x_{min}$ is the minimum value of the indicator; and $x_{max}$ is the maximum value of the indicator.

Subsequently, all ten indicators of the CVOR framework were given weights based on experts' opinions (see coefficients in the "Ecological security evaluations" box in Figure 2). A total of ten experts with backgrounds covering natural resource management, landscape ecology and geography were invited online to participate in the research via email. Accordingly, the ecological security of the YREB in 2015 and 2030 can also be evaluated with the natural breaks (Jenks) classification in ArcGIS 10.5 applied, in order to better reveal changes in the ecological security of the YREB between these two years. As a result, the degree of ecological security can be classified into four categories: I (high), II (relatively high), III (medium) and IV (low), with I indicating the best and IV the worst.

### 2.3. The Land Use Simulation Model LANDSCAPE

The land use simulation model LANDSCAPE was developed based on the Cellular Automata (CA) model. A hierarchical allocation strategy renders the LANDSCAPE model superior to other traditional models in performing interactions between multiple land use types [25]. As requested by the model, land use types are classified into active and passive types depending on whether they are directly demanded by people [30]. These two land use types can be allocated to two interactive processes. Specifically, the active type is allocated hierarchically according to the sequence of aggressiveness, subsequently changes to the passive type are driven by the changes of the active land use type. Of active land use types, urban land is the most aggressive and is allocated in priority, followed by a less competitive alternative.

The LANDSCAPE model enables users to meet the requirements posed by particular demands and constraints. More specifically, the transfer rule of one land use type changing into another depends on both suitability and resistance. Suitability represents the suitability degree to which a location changes from one land use type to a targeted alternative with regard to influencing factors. Resistance indicates the difficulty of changing between one land use type and another based on the original land use map and the resistance coefficient of each land use type. In this study, urban expansion follows the rules of location, suitability and resistance in line with [25], influencing the spatial pattern of cropland loss due to urbanization. To compensate for the cropland occupied, the same quantity of cropland should be reclaimed from ecological lands somewhere else. Compensated croplands are reclaimed as a priority where the agricultural productivity potential is higher and the location is closer to an urban area. A corresponding parameter of resistance in the LANDSCAPE model can be set up for the land use simulations in 2030 for different scenarios [25].

### 2.4. Data Sources

The data used for the CVOR evaluation are shown in Table 1.

**Table 1.** Data description for the CVOR framework.

| Dataset | Data Description | Indicator of CVOR Framework | Usage |
|---|---|---|---|
| Land use data | Land use in 2000, 2015 | For the evaluation of CVOR indicators:<br>• Carbon storage<br>• Water yield<br>• Water purification<br>• Habitat quality<br>• Mean patch density<br>• Shannon's diversity index<br>• Largest patch index<br>• Contagion | / |
| Area of urban land | Area of urban land from 2008 to 2016 | / | To predict the area of urban land in 2030 |
| Topographic data | Elevation | For the evaluation of CVOR indicators:<br>• Water yield<br>• Water purification | / |
| Traffic data | The distance to the nearest national road<br>The distance to the nearest provincial road<br>The distance to the nearest major road | For the evaluation of CVOR indicator: habitat quality | To derive for one of the threats of habitat quality |

**Table 1.** *Cont.*

| Dataset | Data Description | Indicator of CVOR Framework | Usage |
|---|---|---|---|
| Soil data | Root restricting layer depth | For the evaluation of CVOR indicator: Water yield | To derive for the carbon pool |
| | Plant available water content | For the evaluation of CVOR indicator: Water yield | / |
| Meteorological data | Average annual precipitation | For the evaluation of CVOR indicators: • Water yield • Water purification | To derive for nutrient runoff proxy |
| | Potential evapotranspiration | For the evaluation of CVOR indicators: Water yield | To derive for reference evapotranspiration |
| NPP | NPP in 2015 | For the evaluation of CVOR indicator: NPP | / |
| NDVI | NDVI in 2015 | For the evaluation of CVOR indicator: NDVI | / |

A description of the data and data sources is provided in Table 2.

**Table 2.** Data description and data sources.

| Dataset | Data Description | Data Processing | Data Type | Resolution | Sources |
|---|---|---|---|---|---|
| Land use data | Land use in 2000, 2015 | / | Raster | 500 m | Data Centre of Resources and Environment, Chinese Academy Science (CAS) |
| Area of urban land | Area of urban land from 2008 to 2016 | | Statistical data | / | Chinese statistical yearbook (2009–2017) |
| Topographic data | Elevation | Hydrology in ArcGIS | Raster | 500 m | The Shuttle Radar Topography Mission (SRTM) |
| Traffic data | The distance to the nearest national road | Euclidean distance in ArcGIS | Raster | / | Department of Transportation of China (http://jtt.hubei.gov.cn/) |
| | The distance to the nearest provincial road | | Raster | / | |
| | The distance to the nearest major road | | Raster | / | |
| Soil data | Root restricting layer depth | / | Raster | 500 m | The China Soil Database; Soil survey data (The second national soil survey) |
| | Plant available water content | / | Raster | 500 m | |
| Meteorological data | Average annual precipitation | Kriging's interpolation method in ArcGIS | Raster | 500 m | The Chinese Meteorological Administration (CMA) |
| | Average annual accumulated temperature | Kriging's interpolation method in ArcGIS | Raster | 500 m | |
| | Potential evapotranspiration | Calculated annually using the Hamon equation based on precipitation data ([31,32]) | Raster | 500 m | |
| NPP | NPP in 2015 | | Raster | 1000 m | Data Centre of Resources and Environment, Chinese Academy Science (CAS) |
| NDVI | NDVI in 2015 | | Raster | 1000 m | |

## 3. Results

### 3.1. Land Use Simulations with the LANDSCAPE Model

Based on the area of urban land from 2008 to 2016 (Appendix A, Table A1), a logarithmic function indicates that the demand for urban land was projected to be 22,880 km$^2$ in 2030. Using a calibrated LANDSCAPE model, the land uses of the YREB in different scenarios in 2030 were simulated (Figure 3). The process of the LANDSCAPE model's calibration is shown in Appendix A, Table A4.

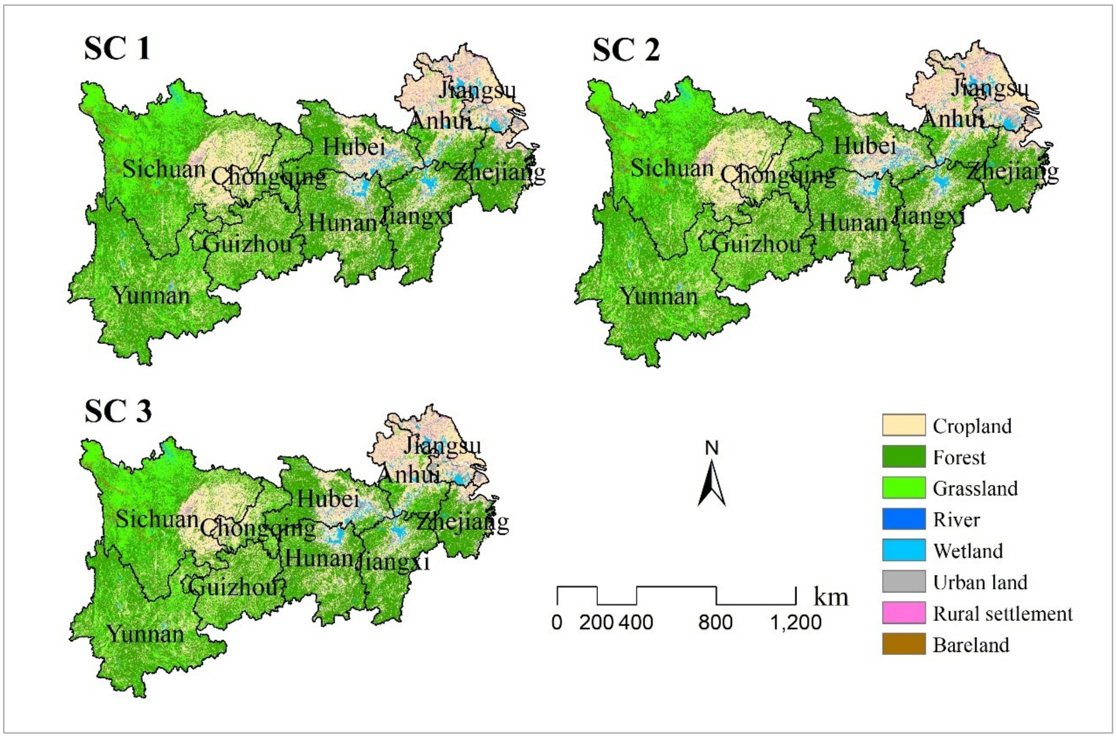


**Figure 3.** Land use simulation of different scenarios in the YREB in 2030.

The land use simulations of different scenarios in 2030 show the overall stable quantity of each land use type compared to that in 2015 (Figure 4 and Table 3). The YREB is predominated by forest (about 46%), followed by cropland (about 30%) and grassland (about 16%). The area of wetland is similar to that of rural settlements (about 2.3%), with urban land representing about 1.13%, bareland is 0.8%, and river is just 0.67%.

Changes in land uses from 2015 to 2030 were most substantial in urban land, with an increase of 31% in both scenarios. A slight increase in cropland occurred due to cropland reclamation. By contrast, there was a slight decrease in rural settlements (about 7%), wetland (about 3%), grassland (about 0.05%) and bareland (about 0.04%). The area of river remained the same by following the ecological protection policy.

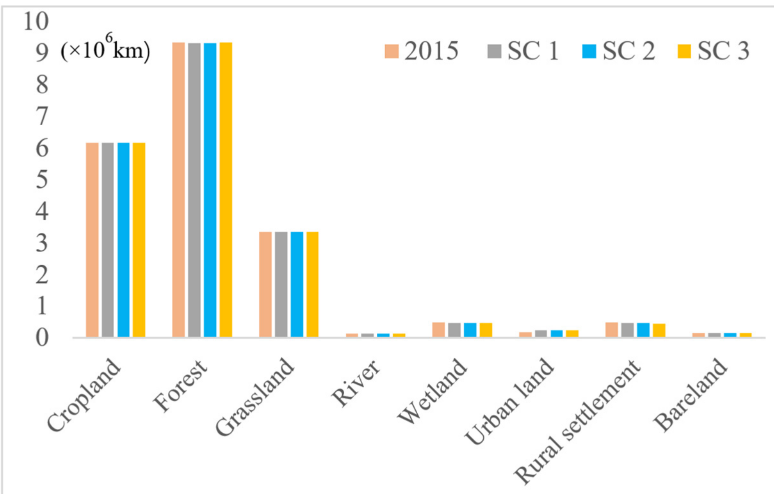


**Figure 4.** Areas of each land use in 2015 and different scenarios in 2030.

**Table 3.** Proportions (%) of land use types and land use changes in the YREB.

| Land Use Type | 2015 | SC 1 | SC 2 | SC 3 | Change of SC1 (2015–2030) | Change of SC2 (2015–2030) | Change of SC3 (2015–2030) |
|---|---|---|---|---|---|---|---|
| Cropland | 30.40 | 30.40 | 30.40 | 30.40 | 0.0002 | 0.0008 | 0.0018 |
| Forest | 45.97 | 45.93 | 45.93 | 45.98 | −0.0917 | −0.0922 | 0.0125 |
| Grassland | 16.48 | 16.47 | 16.47 | 16.47 | −0.0452 | −0.0458 | −0.0508 |
| River | 0.67 | 0.67 | 0.67 | 0.67 | 0.0000 | 0.0000 | 0.0000 |
| Wetland | 2.43 | 2.32 | 2.32 | 2.31 | −4.2329 | −4.2370 | −4.7425 |
| Urban land | 0.86 | 1.13 | 1.13 | 1.13 | 31.0349 | 31.0349 | 31.0349 |
| Rural settlement | 2.39 | 2.28 | 2.28 | 2.24 | −4.7859 | −4.7736 | −6.2302 |
| Bare land | 0.81 | 0.80 | 0.80 | 0.80 | −0.0367 | −0.0428 | −0.0428 |

Changes in each scenario (2015–2030) were calculated by the area in 2015 minus areas in 2030, and then divided by the area in 2015, respectively.

Comparing the changes in land uses from 2015 to 2030 of different scenarios, the area of cropland increased the most in SC3 and the least in SC1. The losses in grassland, wetland and rural settlements occurred most in SC3. Areas of urban land and river remained the same. A significant difference between the three scenarios occurred in forests, with a decrease in SC1 and SC2, but an increase in SC3 as a result of requesting that lands ≥25° return to ecological lands in SC3.

### *3.2. Evaluation of Ecological Security with the CVOR Framework*

The spatial characteristics of ecological security based on the CVOR framework in 2015 and different scenarios in 2030 are presented in Figure 5. The overall spatial characteristics of ecological security appear to be similar in 2015 and 2030. Areas of class I (high) were mainly distributed in the south of the YREB, which was mostly covered by forest, including the majority of Yunnan, Hunan, Jiangxi and Zhejiang. Areas of class II (relatively high) were found to be concentrated in the northwest of Sichuan, the west of Hubei and across the majority of Jiangsu and Anhui, while areas of class III (medium) were mainly scattered throughout the study area. In addition, areas of class IV (Low) were concentrated in a small part of Jiangsu (the southern part), Zhejiang (the northern part) and Jiangxi (around Poyang Lake in the northern part).

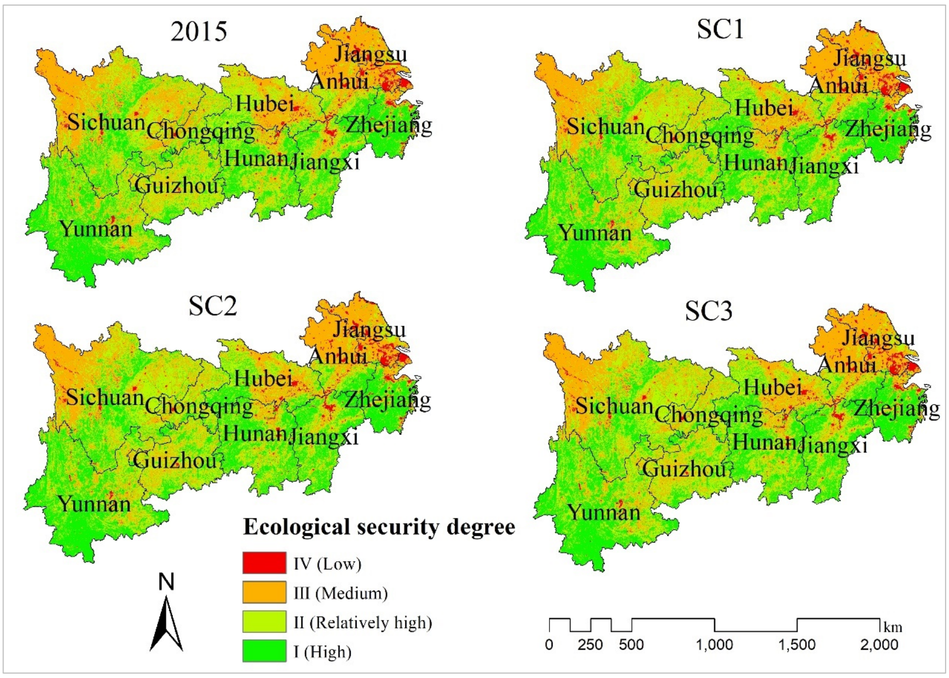


**Figure 5.** Ecological security of the YREB in 2015 and 2030.

The proportions of ecological security of each degree were similar in 2015 and different in 2030 (Table 4): areas of class III (medium) ranked highest (about 37%), followed by class IV (low) (about 30%) and class II (relatively high) (about 30%), while those of class I (high) accounted for less than 3%. Compared to 2015, areas of class I (high) and class II (relatively high) tended to decrease slightly, while classes III (medium) and IV (Low) manifested a general increase in 2030 for all scenarios. Among all the scenarios in 2030, there were more class III (medium) and class IV (low) areas in SC1 than in SC2 and SC3.

**Table 4.** Degree of ecological security of the YREB in terms of quantity and proportion.

| Degree of Ecological Security | 2015 ($km^2$) | SC1 ($km^2$) | SC2 ($km^2$) | SC3 ($km^2$) | 2015 (%) | SC1 (%) | SC2 (%) | SC3 (%) |
|---|---|---|---|---|---|---|---|---|
| I (High) | 60,069 | 54,383 | 54,384 | 54,380 | 2.96 | 2.68 | 2.68 | 2.68 |
| II (Relatively high) | 650,115 | 598,382 | 601,336 | 603,558 | 31.99 | 29.46 | 29.59 | 29.70 |
| III (Medium) | 746,364 | 743,137 | 762,253 | 759,736 | 36.72 | 36.58 | 37.50 | 37.38 |
| IV (Low) | 575,864 | 635,510 | 614,439 | 614,738 | 28.33 | 31.28 | 30.23 | 30.25 |

### *3.3. Changes in Ecological Security between 2015 and 2030*

According to the spatial characteristics, the changes in ecological security between 2015 and 2030 appeared to be similar in different scenarios (Figure 6). Areas where ecological security improved were concentrated in the boundary areas between Sichuan and Chongqing as well as in the west of Hubei. By contrast, areas where ecological security was projected to deteriorate covered the majority of the west of the YREB and were scattered throughout the rest of the study area.

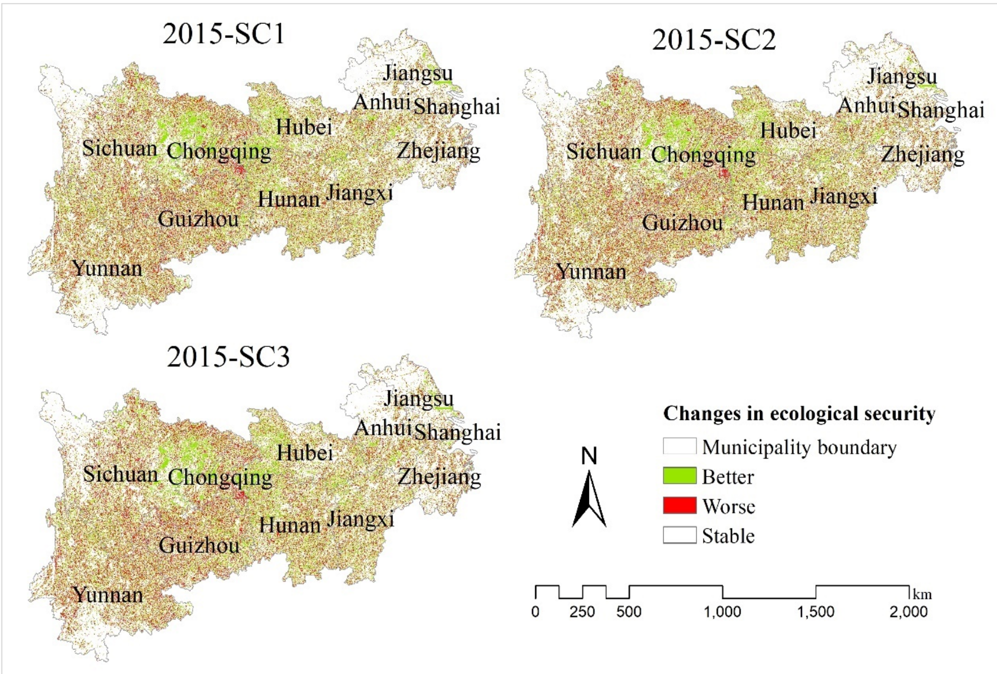


**Figure 6.** Changes in the ecological security of the YREB between 2015 and 2030.

According to the changes in the ecological security of the YREB between 2015 and 2030 in different scenarios (Table 5), about 62% of the areas were projected to remain stable during this period, while approximately 17% were projected to improve and about 21% were projected to deteriorate.

**Table 5.** Changes in ecological security of the YREB between 2015 and 2030 (%).

| Improved | 2015–2030 (SC1) | 2015–2030 (SC2) | 2015–2030 (SC3) | Deteriorated | 2015–2030 (SC1) | 2015–2030 (SC2) | 2015–2030 (SC3) | Stable | 2015–2030 (SC1) | 2015–2030 (SC2) | 2015–2030 (SC3) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| IV–III | 7.41 | 7.80 | 7.78 | III–IV | 9.89 | 9.33 | 9.34 | IV–IV | 19.86 | 19.46 | 19.46 |
| IV–II | 1.03 | 1.04 | 1.06 | II–IV | 1.46 | 1.33 | 1.34 | III–III | 19.56 | 20.08 | 20.01 |
| IV–I | 0.03 | 0.03 | 0.03 | II–III | 9.36 | 9.39 | 9.35 | II–II | 20.61 | 20.70 | 20.74 |
| III–II | 7.13 | 7.17 | 7.22 | I–IV | 0.11 | 0.11 | 0.11 | I–I | 1.93 | 1.93 | 1.93 |
| III–I | 0.15 | 0.15 | 0.15 | I–III | 0.24 | 0.24 | 0.24 | | | | |
| II–I | 0.56 | 0.56 | 0.56 | I–II | 0.67 | 0.67 | 0.67 | | | | |
| Sum | 16.31 | 16.75 | 16.80 | Sum | 21.73 | 21.07 | 21.05 | Sum | 61.96 | 62.18 | 62.15 |

I, II, III and IV denote ecological security of high, relatively high, medium and low degrees, respectively.

## 4. Discussion

### *4.1. The LANDSCAPE Model for Simulating Land Uses in Different Scenarios*

Certain models can simulate the spatial characteristics of land use, including CLUE [33], FLUS [34] and Land Scanner [35]. The LANDSCAPE model was applied in this study due to its superior simulation accuracy and, more importantly, its hierarchical allocation strategy, which allows for an explicit determination of the allocation sequence among multiple land uses [25]. This fit particularly well to our case, which revealed cropland reclamation resulting from urban expansion in a hierarchical allocation strategy of land use change, first of urban expansion (during which cropland is occupied), followed by cropland reclaimed from ecological lands (SC1, SC2 and SC3) and reclaimed cropland $\geq 25°$ returning to ecological lands (SC3).

With the LANDSCAPE model, the projected land uses in 2030 only simply considered two constraints: (1) urban expansion takes place in areas more adjacent to city edges, and (2) cropland reclamation is a priority where agricultural productivity potential is higher. It should be acknowledged that simulated maps can differ from the reality due to the neglect of other factors, such as ecological protection policies, socio-economic development plans and spatial planning. However, the advantage of considering such simple constraints is to highlight the impact of cropland reclamation on ecological security rather than other factors.

### *4.2. Evaluation of Ecological Security with the CVOR Framework*

The CVOR framework focuses on the integration of ecosystem services and ecosystem health, which is in line with the ideas of sustainable development, such as human-nature cohesion development and the ecological construction development strategy relevant to this region. Ecosystems provide different kinds of services of benefit to people. The specific ecosystem services that are considered for the development of the CVOR framework should be typical and relevant to local ecological security. In this case, carbon storage, water yield, water purification and habitat quality are the representative ecosystem services that the ecosystem of the YREB provides.

Ecological security in the YREB in 2015 and different scenarios in 2030 were evaluated by applying the CVOR framework. CVOR performs well in revealing spatial characteristics at a grid level, allowing for an explicit analysis of drivers and dynamics and enabling the prediction of spatiotemporal changes in ecological security. Therefore, the CVOR framework is superior to other models in evaluating ecological security at the grid level, thereby providing a more explicit spatial analysis. For example, PSR (DPSIR) is widely used for evaluating ecological security, while some indicators of the evaluation framework (partly) rely on statistical data which are normally only available at an administrative level, especially socio-economic data [36,37]. In addition, the CVOR framework is advantageous in its flexibility, as it can include indicators specific to a study's aims and the local characteristics of the study area, enabling it to be used widely to evaluate ecological security in different regions [11]. For example, [38,39] have applied ecosystem service value (ESV) as an approach to reflect contributions to the ecological security evaluation, rather than our qualification of specific ecosystem services. However, if ecological security needs to focus on the demographic aspect, this framework performs more poorly because socio-economic data tend to be available at the municipal scale rather than at the grid scale. This may be a limitation, as demographic factors play a more important role in influencing ecological security, especially in urban agglomerations [40].

### 4.3. Changes in Ecological Security from 2015 to 2030

#### 4.3.1. Changes in the Ecological Security of All Scenarios

The changes in the ecological security of the YREB from 2015 to 2030 in different scenarios exhibited some similarities. This was mainly due to the quantity of newly added urban land in 2030 being limited. The demand for urban land of the YREB in 2030 is projected to account for only 1.13% across the study area; therefore the change in the urban land area from 2015–2030 would be much less than this quantity. In addition, compared to SC2, the reclaimed croplands (>25°) that need to return to ecological lands in SC3 were concentrated in the parts of Sichuan, Chongqing, Hubei, Jiangsu, Shanghai and Zhejiang where broad and connected croplands are distributed.

Overall, the results reveal that ecological security is overall stable, covering about 62% of areas (Table 5). This corresponds to the stable land use pattern during this period. Changes in the degree of ecological security in the YREB during this period are also obvious to see. Specifically, areas showing an increase in their degree of ecological security were mainly distributed in places predominated by broad and connected cropland (Figure 6). This is in line with the findings of [10] showing lower ecological security in these areas in 2015. In the meantime, the moderate decrease in areas of class I (high) and class II (relatively high) from 2015 to 2030 indicates that ecological security overall will deteriorate in the YREB. This suggests that we cannot ignore the negative role of cropland change (both cropland reclamation and cropland returning to ecological lands) in influencing ecological security. This finding is consistent with studies emphasizing the need to avoid unreasonable land reclamation and suggesting an optimized landscape structure to improve ecological security [10,41].

Urbanization has been documented as a negative impact on ecological security. For example, [11] found a decrease in ecological security in urban agglomerations in Hunan, Hubei and Jiangxi between 2000 and 2015, while [4] revealed the effect of urban expansion on ecosystem health in southwest China (specifically the capital cities in Yunnan, Sichuan, Chongqing and Guizhou). Similar findings have been attained in the Pearl River delta [42] (Li et al., 2020). Some case studies have also focused on the city level, such as [43] in Yuxi in Yunnan, revealing that flat cropland appears to have lower ecological security than mountainous cropland due to urban expansion. In line with these findings, our results suggest a higher proportion of changes in ecological security around urban areas, especially capital cities such as in Hunan, Hubei, Jiangxi and Anhui. This indicates that cropland changes intensify the reduction in ecological security at the boundaries of urban agglomerations.

#### 4.3.2. Comparison of Changes in Ecological Security in Different Scenarios

A greater change in the ecological security of the YREB between 2015 and 2030 was identified in SC1 compared to in SC2 and SC3. More specifically, there were higher proportions of class III (medium) and class IV (low) areas in SC1 compared to in the other two scenarios. This indicates that cropland reclamation constrained by a slope $\geq 25°$ helps maintain a good level of ecological security. This can be partly related to the improvement of the contribution aspect of the CVOR framework: an increase in forest facilitates the provision of ecosystem services such as carbon storage and habitat quality [44].

Interestingly, in areas whose ecological security is deteriorating, a larger proportion was revealed in SC2 (21.07%) compared to in SC3 (21.05%). This may be due to the fact that cropland returning to ecological lands enhances land use change and correspondingly influences landscape metrics including landscape heterogeneity and landscape connectivity. Cropland reclamation occurs in the case of other land use types, such as forests, wetlands and grasslands, which can be scattered. It also inevitably alters landscape metrics like landscape heterogeneity and connectivity [45,46]. This is reflected by the change in the organization aspect of the CVOR framework, and represents a further impact on ecological security.

The Grain for Green program has been deemed helpful in improving ecological security, because it facilities an increase in vegetation cover [44,47], although this contradicts our finding, because the general negative impact on ecological security shown in SC2 was more significant than that in SC3. This indicates that an increase in ecosystem service provision does not always mean an improvement in ecological security, and implies that the enhancement of one aspect alone does not work for the improvement of ecological security, which lies in the maximization of the common value of ecosystem function and structure. Therefore, other potential undesired effects should be considered in the implementation of land use policies.

There are some limitations to be acknowledged. First, regarding the contribution of the CVOR framework, there are some other services that play an important role in maintaining ecological security in the YREB, such as soil formation, flood regulation and biodiversity, but it was impossible to include them all in this study. Second, there are multiple factors that may influence ecological security in the YREB. Although focusing on the role of cropland reclamation has helped answer this study's research question, other influencing factors should be considered in future investigations to mitigate potential biases.

## 5. Conclusions

Ecological security was evaluated by applying the CVOR framework in the YREB, China. With the LANDSCAPE model, land uses in 2030 were projected based on three scenarios of cropland reclamation. The results show that ecological security is projected to remain stable on the whole between 2015 and 2030 in different scenarios, with about 62% of areas remaining unchanged. The most significant changes are projected to occur in Sichuan, Chongqing, Jiangsu, Shanghai and Zhejiang, where broad and connected croplands are distributed. SC2 and SC3 are likely to have a less significant impact on ecological security than SC1, especially in the upper reaches of the YREB, where croplands $\geq 25°$ are concentrated. This study highlights the role of cropland change (both cropland reclamation and cropland returning to ecological lands) in influencing ecological security. Therefore, cropland protection policies should not ignore potential undesired effects that may threaten ecological security.

Some studies have included demographic factors to evaluate ecological security, but this was not the case here. Therefore, future studies should address these factors to further display the characteristic of ecological security. In addition, future research should aim to reveal the driving factors of changes in ecological security, which help regulate ecological security in the YREB.

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## Appendix A

**Table A1.** Areas of land uses from 2008 to 2016.

| Year | Area of Urban Land | Year | Area of Urban Land |
|---|---|---|---|
| 2008 | 460.00 | 2013 | 543.28 |
| 2009 | 466.60 | 2014 | 552.61 |
| 2010 | 484.01 | 2015 | 566.13 |
| 2011 | 506.42 | 2016 | 585.61 |
| 2012 | 520.30 | | |

Unit: $km^2$.

**Table A2.** Clarification of changes in land use area in 2030 compared to 2015.

| Land Use Type | Cropland | Forest | Grassland | River | Wetland | Urban Land | Rural Settlements | Bareland |
|---|---|---|---|---|---|---|---|---|
| 2015 | 6.17 | 9.33 | 3.34 | 0.14 | 0.49 | 0.17 | 0.49 | 0.16 |
| 2030 | ≥6.17 (depends on changes in urban land area from 2015 to 2030) | | | =0.14 | | >0.17 (predicted with historical data) | | |

Unit: $\times 10^6$ $km^2$.

**Table A3.** Resilience coefficients of each land use type.

| Land Use Type | Resilience Coefficient |
|---|---|
| Cropland | 0.45 |
| Forest | 1.00 |
| Grassland | 0.70 |
| River | 1.00 |
| Wetland | 0.85 |
| Urban land | 0.20 |
| Rural settlements | 0.25 |
| Bare land | 0.00 |

**Table A4.** Kappa simulation values of the LANDSCAPE model.

| | Cropland | Forest | Grassland | River | Wetland | Urban Built-Up Area | Rural Settlement | Bare-Land |
|---|---|---|---|---|---|---|---|---|
| Kappa Simulation | 0.333 | 0.140 | 0.218 | N/A | 0.270 | 0.521 | 0.298 | 0.296 |

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