# Exploration on Ant Colony Optimization for Optimizing Land Use Spatial Allocation

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**Abstract:** The purpose of optimizing the allocation of land use (LU) space is to enable effective utilization of land resources in various regions, in order to maximize the economic and social benefits of limited land area. The upper reaches (UR) of the Yellow River are important agricultural production bases and ecological barriers in China, and optimizing land space is of great significance for promoting agricultural development and protecting the ecological environment. Therefore, the optimization method based on ant colony optimization (ACO), as a new type of optimization algorithm, has strong adaptability, robustness, and global search ability, which can effectively solve the problem of LU spatial optimization configuration. This article determined the definition and constraints of land issues, and set relevant parameters. The steps of the ACO were analyzed, and the results of the algorithm were analyzed and evaluated. The LU situation in the UR of the Yellow River was analyzed using survey methods and statistical analysis. The results showed that the patch density index before and after optimization in various regions was generally small, with the index values of forest land and construction land being 0.1142 and 0.2975, respectively.

**Keywords:** Ant Colony Optimization, Land Use, Spatial Optimization, Upper Reaches of the Yellow River

## 1. Introduction

The optimal allocation of LU space refers to the maximization of land resource utilization and minimization of waste through rational planning and management of land resources. There are many shortcomings in traditional LU planning methods. Group algorithms have been widely applied in many fields, including transportation planning, logistics distribution, and power system optimization. In terms of optimizing the allocation of LU space, ACO has been applied in practical projects. The application of ACO in optimizing the allocation of LU space can effectively improve the efficiency of land resource utilization and reduce waste and pollution, which has important practical significance and application value.

Land resources are the foundation for human survival and development. How to scientifically and reasonably allocate land resources has become the most important

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and urgent issue in solving various types of land conflicts. Junchuan Fan believed that the combination of spatial distribution, semantic features, and temporal dynamics of points of interest within a geographical area helps to capture its unique LU characteristics. Previously, research on LU modeling based on interest points mainly focused on geographical regions, selecting spatial scales and semantic granularity to represent LU. He developed a scalable LU model and tested the impact of these three factors on LU characteristics using data from three geographical regions [1]. Ahmad Shakib Sahak used a random forest monitoring classifier to divide Kabul City into four different LU/land cover categories (vegetation, water, buildings, and bare land). Remote sensing technology has been proven to be effective and economical, especially in minimizing the time required to evaluate urban heat island changes based on the relationship between surface temperature and LU/ changes of LU [2]. Saba Farshidi pointed out that in recent years, there have been significant changes in LU and cover, especially in areas with strong climate change and population growth. Land cover change assessment is the most accurate method for understanding past LU and predicting future changes [3]. Based on ACO, this article studied the optimization problem of LU space. In the process of developing and utilizing land resources, it is necessary to scientifically and reasonably plan urban land and divide it into several levels based on different functional zoning within the region.

This article first described the ecological environment of cities in the UR of the Yellow River and analyzed its causes. Secondly, the ecological suitability of the Yellow River Basin was elaborated, and the ecological protection and high-quality development of the UR of the Yellow River were proposed. Then, a theoretical description of the "Three Lives" space was provided, and analysis and discussion were conducted based on the specific situation in the UR of the Yellow River. Finally, through investigation, the optimization of LU space was explored.

## 2. Optimized Allocation of Land Use Space

### 2.1 Ecological Environment of Cities in the Upper Reaches of the Yellow River

The UR of the Yellow River have typical arid and cold arid climate characteristics, mainly characterized by low annual precipitation, most of which is concentrated in summer and autumn, with cold and dry winters and short and hot summers. In terms of hydrology, the UR of the Yellow River are the birthplace of the Yellow River, and the river's water volume mainly depends on rainfall and snowmelt. The hydrological characteristics are characterized by large fluctuations in annual water volume and significant interannual changes. For a long time, there has been a contradiction between supply and demand of water resources in the UR of the Yellow River. The UR of the Yellow River are dominated by agriculture as the economic industry, mainly growing crops such as wheat, corn, and apples. In addition, the area also has abundant mineral resources such as coal and iron ore, which play an important supporting role in the local economic development. The terrain in the UR of the Yellow River is complex and diverse, including types of landforms such as high mountains, canyons, and plateaus. They provide unique natural landscapes and resource environments.

The UR of the Yellow River are the center of ecological protection and high-quality development in the entire Yellow River basin. Its climate and environment are very unique, as are ecological protection and social development. The UR of the Yellow River are located in the transitional zone between the first and second stages of landforms in China, with different climate types and uneven rainfall. The UR of the Yellow River exhibit a special hydrogeological relationship of "low water and high land", with a trend of warming and humidifying the climate, and significant spatial differences in the climate environment. The high dependence of the UR of the Yellow River on climate and the enormous fluctuations in climate itself pose significant risks to water resource security. The poor coordination of climate resources in the region has caused serious ecological and agricultural vulnerability. The region is not only facing more severe climate change, but is also more sensitive to climate change. In addition, "low water and high land" and severe river drop lead to low efficiency in water resource utilization, and salinization of irrigated land leads to a decrease in the quality of agricultural development.

Some cities have unequal LU due to historical reasons and improper planning, such as improper agricultural LU and excessive urban LU. This has led to a decrease in agricultural resources and urban expansion that has damaged the ecological environment [4-5]. In urban construction, there is a waste of land resources in some places, manifested as a large amount of fallow land and inefficient utilization. This not only wastes valuable land resources, but also increases the operating costs of the city and has a negative impact on the ecological environment. Driven by economic development, it is facing rapid urban expansion. This has led to problems such as the decline of urban infrastructure, road congestion, and lack of social resources. Meanwhile, the rapid expansion of cities can easily lead to an increase in land development intensity and pollution of the ecological environment. Accelerating urbanization is gradually widening the development gap between some rural areas and cities. There are significant differences in infrastructure, public services, and other aspects between rural and urban areas. The uneven distribution of land resources has also caused an income gap between farmers and urban residents [6-7]. In the pursuit of economic development, insufficient attention is paid to protecting the ecological environment, leading to large-scale land reclamation, excessive development of water resources, and pollution. This not only directly affects the stability and biodiversity of ecosystems, but also poses risks to environmental issues and a decline in the quality of human social life.

### 2.2 Ecological Suitability

The UR of the Yellow River have diverse natural ecological environments and abundant biological resources. However, due to factors such as arid climate, human activities, and degradation, the ecosystem in the region is vulnerable to damage. Therefore, strengthening ecological protection and restoration work is crucial for the sustainable development of the UR of the Yellow River. At the same time, the government is actively promoting the strategy of "ecological zoning" to achieve coordinated economic and ecological development [8-9].

By utilizing the possibility of global warming and humidification, ecological environments can be created in appropriate areas, thereby adjusting the social development structure and establishing a positive interaction model between climate change, environmental protection, and social development. By integrating the water resources and higher solar and thermal energy resources in the UR of the Yellow

River, fully utilizing the advantages of regional land resources, modern water-saving and efficient agriculture can be developed, thereby improving the quality and efficiency of water resource utilization in the Yellow River. On the basis of technological innovation in disaster prevention and reduction, it is necessary to improve the technical level of precipitation, flood forecasting, and climate, environmental, and water security risk assessment in the UR of the Yellow River. It is necessary to strengthen the meteorological disaster warning system in the UR of the Yellow River, strengthen scientific and technological support for ecological construction, water resource allocation, and socio-economic development, in order to ensure the safe development of the Yellow River. By scientifically implementing artificial increase in rainfall (snow) in the UR of the Yellow River, ice and snow protection and ecological restoration work can be strengthened. The stability of the UR of the Yellow River can be improved by increasing the water production and storage capacity of the basin to ensure its immortality.

The ecological protection and high-quality development of the UR of the Yellow River should follow natural laws and fully utilize regional natural resources to form a harmonious model of hydrology, soil, climate, ecology, and humanity. To achieve high-quality development while protecting ecology, the water of the Yellow River must be "clean"; the loess must be "green", and the water must shift from "harmful" to "beneficial" [10-11].

### 2.3 "Three Lives" Space

The distribution of ecological value-added areas is scattered, with other ecological areas transforming into ecological grassland areas, agricultural production areas transforming into ecological areas, grassland ecological areas transforming into aquatic ecological areas, and forest ecological areas being the most important. The spatial classification system of the Three Lives in the Yellow River Basin is shown in Table 1.

**Table 1.** Space classification system of the Yellow River Basin

| First level classification | Secondary classification |
|---|---|
| Production space | Paddy fields, dry land, other forest land, and other construction land |
| Living space | Urban land and rural residential areas |
| Ecological space | Forest land, grassland, lakes, bare rock land and others |

In order to optimize these three living spaces, a comprehensive ecological assessment is needed to understand the current status and potential problems of the urban ecological environment, and to determine priority areas and fragile environments for ecological protection. It is necessary to develop a scientific and reasonable environmental plan, including delineating ecological red lines, ecological compensation mechanisms, etc. It is need to strengthen the protection and restoration of important ecosystems, enhance their resilience and enhance the functionality of ecological services. The scientific layout of industrial zones can promote the optimization and improvement of industrial structure, thereby achieving an organic combination of production and ecological life. Based on urban characteristics and ecological resource equipment, it is necessary to reasonably determine the direction of industrial development to avoid excessive resource development and environmental pollution [12-13]. It is needed to attach importance to the construction of ecological cities, promote green buildings and low-carbon transportation, and reduce natural resource consumption and environmental impact. By strengthening environmental governance and monitoring, sustainable improvement of the ecological environment can be ensured.

## 3. ACO for Land Use Optimization Configuration Model

### 3.1 Basic ACO and Parameter Analysis

ACO is a typical heuristic search method. It mainly relies on pheromones and heuristic functions, analyzing the behavioral characteristics of all individuals on the ant path under known conditions, and optimizing the known parameters to achieve a global optimal solution. In order to improve the efficiency of algorithm optimization, artificial ants can improve performance such as predicting the future and local optimization [14-15]. These behaviors do not exist in real ants. In many specific applications, artificial ants can exchange information with each other during local optimization processes, and there are also improved swarm algorithms where artificial ants can perform simple predictions. Due to the parallelism of swarm algorithms, a large number of ants can improve the overall search ability and ensure the stability of the algorithm [16-17]. However, if the number of ants increases to some extent, it would lead to a large amount of information on the previous research path tending to average, and the positive feedback effect of the information is not significant [18-19]. Heuristic factors reflect the relative importance of the amount of information collected by ants when searching for a population, and have a significant impact on algorithm performance. The greater the value, the more important pheromones become in ant search. The size of the pheromone volatilization factor directly affects the overall search and convergence speed of the algorithm. The pheromone residue factor reflects the intensity of individual interactions between ants [20].

Determining the rational use of LU units is to achieve several goals under certain LU indicators, such as the economic, environmental, and social benefits of LU in the planning area. It is also necessary to combine the natural and socio-economic conditions of different regions and take measures that are suitable for the local situation. In terms of LU efficiency and efficiency, the goal should be conservation and intensification to improve the rationality of resource allocation. In addition to reorganizing and renovating existing land, planning and control efforts should also be strengthened, as well as construction speed. The larger the objective function, the better. The calculation is performed according to Formula (1):

$$\mathrm{m}_{ikt} = \sum_{o=1}^{i} \sum_{k=1}^{N} g(a_{ikt}) \quad (1)$$

Among them, i is the utilization type and N is the number. Similarly, the objective function is calculated using Formula (2):

$$\mathrm{m}_{ikt} = \frac{1}{\alpha + \sum_{o=1}^{i} \sum_{k=1}^{N} g(a_{ikt})} \quad (2)$$

Each ant can obtain heuristic information about assigning different types of LU to each landing unit. Multiple goals are transformed into one goal to simplify the solution process. The overall feasibility of implementing specific behaviors in optimizing LU is calculated:

$$\mathrm{m}_{ik} = \mathrm{m}_{ik1} \times \mathrm{m}_{ik2} \times \mathrm{m}_{ik3} \quad (3)$$

Among them, $\mathrm{m}_{ik1}$ is for the coordination degree of sustainable LU; $\mathrm{m}_{ik2}$ is for the spatial agglomeration function, and $\mathrm{m}_{ik3}$ is for the minimum planning cost function. The process of simulating the exploration of pheromone concentration establishes rules for updating information concentration on any path.

### 3.2 Parameter Settings

This study was conducted on a geographic platform using the spatial optimization module of the platform. This module converted raster data used for adaptive evaluation into a data format that can be recognized by the geographic platform and imported into the platform. The parameters selected in this article were information heuristic coefficient=3, expected heuristic coefficient=4, and volatility coefficient=0.25.

When optimizing regional allocation, the optimization allocation should be evaluated based on the current usage status and adequacy. According to ACO, land allocation is constrained by certain limitations and principles, which are mainly determined by the actual situation of the land allocation process. During the configuration process, area restrictions must be followed, including the total land area and the area of each category. After integrating the above parameters and conditions into the model, the current LU status in the UR of the Yellow River was selected as the known condition. The number of networks was determined based on the LU structure, taking into account two objective conditions of adequacy and compactness, namely the spatial simulation results of simulating LU.

In the results of optimizing the configuration, the number of simulated grids in the average capacity value space is shown in Fig. 1.

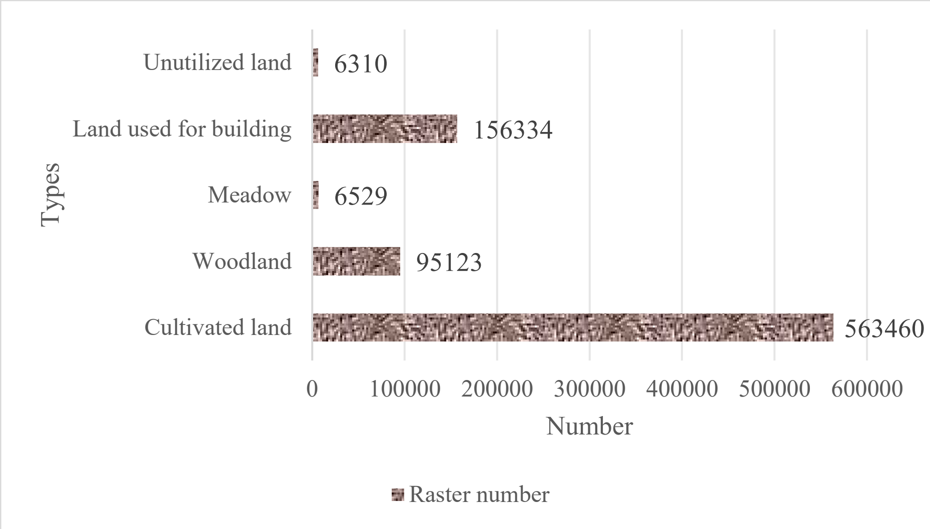


**Fig. 1.** Number of spatially simulated grids

There is no simulated water surface, and the planning method is directly applied to the current LU environment. Unused building plots, farmland, forests, and grasslands were sequentially simulated. Accuracy was checked using the Kappa index, and LU spatial planning was optimized using the constructed ACO model. The number of spatial simulation grids for cultivated land, forest land, grassland, construction land, and unused land was 563460, 95123, 6529, 156334, and 6310, respectively.

### 3.3 Suitability and Optimization of Land Use

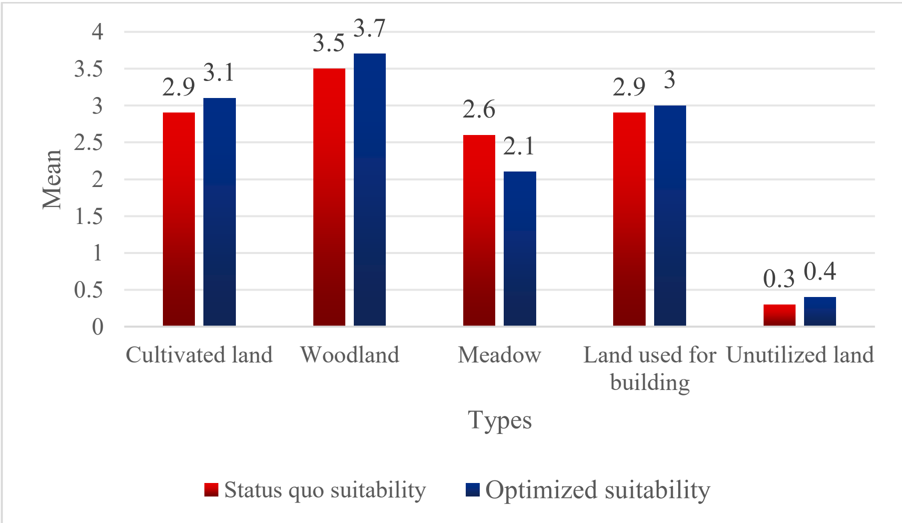


**Fig. 2.** Suitability analysis

In Fig. 2, the current suitability of cultivated land, forest land, grassland, construction land, and unused land reached 2.9, 3.5, 2.6, 2.9, and 0.3, respectively. After spatial optimization, the results obtained also changed. Among them, the suitability of cultivated land, forest land, construction land, and unused land was improved to 3.1, 3.7, 3.0, and 0.4, respectively, while the suitability of grassland decreased.

The average suitability value represents the suitability of a soil unit and can represent the suitability for different soil uses.

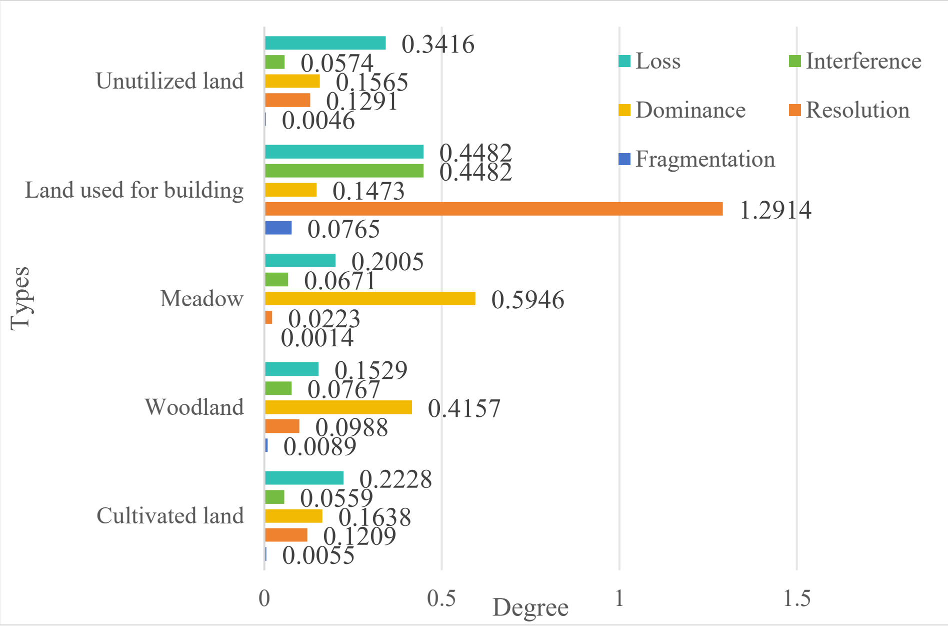


**Fig. 3.** Landscape pattern index statistics

In Fig. 3, the degree of fragmentation of arable land, forest land, and grassland was relatively low, and the separation degree of construction land was much higher than that of other LUs. The interference degree of construction land was the highest. The degree of loss was influenced by the degree of interference, and its trend was the same as the degree of interference. The damage degrees of cultivated land, forest land, grassland, construction land, and unused land reached 0.2228, 0.1529, 0.2005, 0.4482, and 0.3416, respectively, with control degrees of 0.1638, 0.4157, 0.5946, 0.1473, and 0.1565.

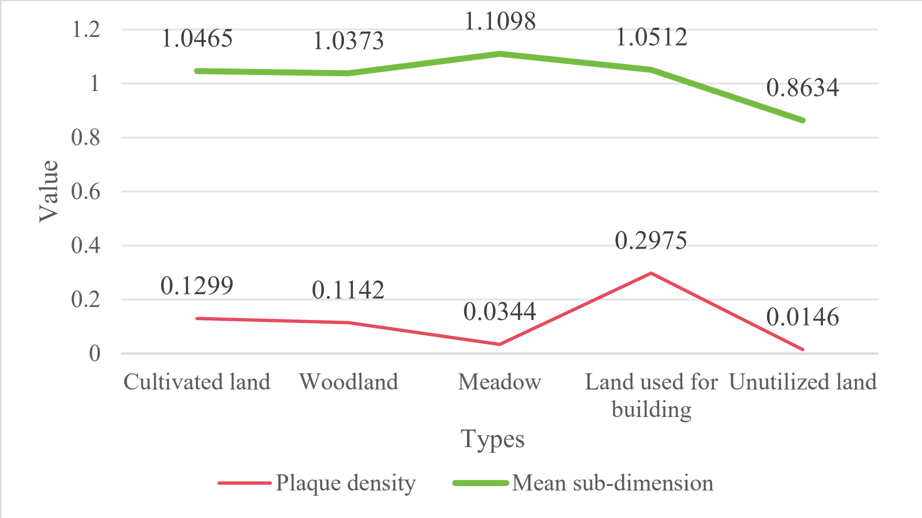


**Fig. 4.** Optimized LU landscape pattern index

In Fig. 4, it can be observed that from the patch density index, the index value of cultivated land was 0.1299, and the index value of grassland was 0.0344. From the perspective of the fractal index, the optimized values of the fractal index for cultivated land, forest land, and construction land were 1.0465, 1.0373, and 1.0512, respectively, indicating a more regular shape. The highest fractal dimension index was found in grasslands, indicating that their boundaries were relatively complex.

## 4. Suggestions for Optimizing Urban Land Space in the Upper Reaches of the Yellow River

Efficient utilization of land resources requires scientific planning and spatial layout, and rational allocation of urban land. By adopting an intensive development model and encouraging the construction of high-rise buildings, LU efficiency can be improved. For resolutely adhering to national farmland protection policies, it is necessary to preserve farmland as much as possible and increase farmland protection efforts during urban expansion. At the same time, it is necessary to strengthen ecological environment protection in order to protect important ecological functional areas and restore and repair damaged ecosystems. By promoting new building technologies and energy-saving and environmentally friendly design concepts, land occupation can be reduced. By encouraging the development of urban green space, the coverage rate of urban green space can be increased and the urban ecological environment can be improved. By properly planning the transportation network, traffic efficiency can be improved, traffic congestion and energy consumption can be reduced. In urban planning, it is necessary to fully consider transportation supporting facilities and develop public transportation, which can encourage non motor vehicle travel and reduce the use of private cars. By promoting agricultural modernization and developing efficient, energy-saving, and environmentally friendly agricultural production methods, comprehensive agricultural benefits can be improved. At the same time, it is necessary to actively develop a circular economy, promote the recycling of resources and the reduction of waste treatment. By clarifying the direction of urban expansion and limiting urban scale, the speed of urban expansion can be controlled to avoid disorderly spread and land waste. The optimal allocation of land resources is to better meet the needs of economic and social development and ecological environment construction. In the case of limited land resources, the optimization goal should be achieved through reasonable regulation, organization, and management of various types of land within the region, guided by the optimal strategy. This invisibly puts forward higher requirements for LU.

## 5. Conclusions

ACO can effectively solve the problem of optimizing LU spatial allocation and quickly converge to the optimal and suboptimal solutions. However, the setting of parameters has a significant impact on the performance of the algorithm. Therefore, this article determined the parameter values of information heuristic factor, expected heuristic factor, and volatility factor. A heuristic optimization strategy and improved random selection method were constructed to optimize land resources. This article verified the application effect of ACO in LU spatial optimization configuration through a case study. The experimental results indicated that it is necessary to develop scientific and reasonable land planning and management measures, and strengthen the protection and effective utilization of urban land resources in the UR of the Yellow River, in order to promote urban-rural integration and sustainable economic and social development.

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