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*Article*

# Study on the Construction of Landscape Ecological Classification System for Large-Scale Coal-Power Base in Semi-Arid Steppe Region

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**Abstract:** The ecological background condition of the semi-arid steppe region (SASR) is extremely fragile. It is recognized that the development of coal and electricity power is a kind of strong human interference behavior for regional landscape ecology. Landscape ecological classification (LEC) is the premise of landscape ecology research of the mining area. The current research on the SASR and grassland LEC of coal-power base is relatively less, but still remains uncertainty concerning how to stratify and classify urban mining landscapes into units of ecological significance at spatial scales appropriate for management. This study is based on hierarchy theory, scale theory, landscape process, the patch-corridor-matrix model, the network, the theory of multiple planning integration and the principle of remote sensing. According to the comprehensive principle, principles of the combining of structure and function, principle of the combining human-ominated and natural landscape, principle of emphasis, and principle of combining qualitative analysis with quantitative research of LEC in large-scale coal-power base(LSCPB). On the basis of occurrence method land classification, fully consider the ecological attributes of the land, integration pattern, processes and function theory of the landscape ecology, the LEC system of the LSCPB in the SASR has been constructed by using top-down decomposition classification method. Empirical research of the Victory and Mindong No.1 mining areas of Shenhua Group shows that the classification system constructed in this paper can meet the requirements of LEC and fully reflect the status of landscape ecology of LSCPB in SASR. This study can provide theoretical guidance for the landscape ecology of LSCPB, while also supporting a theoretical reference for the LEC research.

**Keywords:** Semi-Arid Steppe Region•Large-Scale Coal-Power Base•Landscape Ecological Classification

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## 1. Introduction

Coal is the most important component of the world's energy structure and the most important energy source for the Chinese economy (Edenhofer et al. 2015). With the development of social economy, the demand for mineral resources is increasing, which has pulled or stimulated the rapid development of the mining industry. In turn, the mining industry has promoted the rapid development of social economy (Bian 2015). In order to further meet China's energy demand, the Chinese government focused on the construction of Eastern

Inner Mongolia 14 other large-scale coal bases and 16 LSCPB in the "12th Five-Year" period. For decades, rapid economic growth and the improvement of human living status for China—— the world's biggest population have been accomplished at the expense of environmental integrity (Fu 2008). Grassland accounts for about 20% of the total land area of the world (Han et al. 2012). Serious degradation of semiarid grasslands worldwide has negative consequences for local, regional, and global ecosystem services (Chen et al. 2017). The long-term high intensity mining of coal leads to the desertification of land, spread of pollution, landscape fragmentation, degradation of habitat and landscape ecological functions, and ecological imbalances in SASR. The mining area LEC is the basis of the analysis and simulation of landscape pattern in the mining area, the basic way of clarifying the influence mechanism of mineral exploitation on regional landscape ecology, is the premise to carry out the study on landscape ecological restoration in mining area. The research on the theory and methodology of LEC of the mining area, to a large extent, reflects the whole study level on landscape ecological restoration of mining area.

The landscape classification is based on differences in the materials of the landsacape, the energy distribution and forms of exchange, the influence of human activities on the landscape, and the culture that people attach to the production and life of the landscape, depending on the hydrothermal condition of the landscape system. According to specified principles, an analysis of the natural attributes of the landscape, ecological functions and spatial configuration characteristics was conducted, with a series of indicators to characterize these differences. Then the landscape types were divided and merged, and the landscape ecology classification system was conducted (Fu et al. 2001). In the field of LEC research, the Soviet Union (А.Г.Исаченко 1992) and others understood landscape as a certain level of classification units from the perspective of geography. The LEC for the North American School of (Forman 1986) and others transformed land use classification systems, because they paid attention to research on landscape patterns and ecological functions. The European school was a birthplace of LEC, Westerveld (et al. 1984), Naveh (et al. 1984) and others focused on landscape classification systems based on the grade and strict LEC. Chinese scholars (Wang 1996), (Xiao et al. 1998) and others introduced foreign LEC theory into China, then Cheng (2002), Zhou(1999), Guo (et al. 2008) and Li (et al. 2005) and others put the theory into practice in order to solve the problem of regional ecological environments. The current status of LEC research is mostly limited to macroscopic classification of large and mesoscale landscapes, and less involved in division of small scale landscape types, especially the classification of severe human disturbance in mining areas. In recent years, the development and management of a single mineral resource has produced a series of serious social and ecological consequences, emphasizing that the ecological classification of mining scales according to ecological attributes has gradually become a hot topic.

At present, most of the LEC of mining areas draws on the existing land cover and LEC systems such as "the second national land survey technical regulations(TD/T1014-2007)"(Han et al. 2012), or land use classification systems adapted to the actual research needs(Hendrychová et al. 2016). The landscape is divided into four categories: natural landscape (mountain, water, desert, grassland, forest vegetation, etc.), agricultural landscape (farmland, artificial woodland, orchard and vegetable land), artificial landscape (mining industrial buildings, workers' living area buildings, gangue heaps, open-pit mining, open-pit mine dumping) and anthropogenic landforms (landslides, eroded landforms, desertified land, coal mining subsidence ponds, swamps and hydro-water basins), according to the influence and extent of human production and mining activities (He et al. 2000). According to the three basic functions of biological production, environmental services and cultural support of landscape ecosystems, the landscape ecology of mining areas is divided into three categories: mining large agricultural area (farming area, commercial fruit-growing area, aquaculture area and grassland area); capital construction areas (mining facilities, etc.); environmental protection and service functions (after reclamation, tourism, etc.) (Wang et al. 2001). Wang et al. (2007) had constructed three categories of landscape types (strong human disturbance zones), landscape system (land cover zones), landscape components (geomorphology and soil type zones) according to high diving coal mining area of eastern China by using high resolution remote sensing images. Zhang et al. (2011) established a framework of spatial control planning and design of landscape elements from ''macro control, medium allocation and micro optimization'' for the purpose of managing and using these special landscape resources, then divided mining landscapes into restoration landscapes (coal gangue, waste yards, surface cracks, subsidence), limited restoration landscapes (watershed, settlement, industrial facilities, roads) and protection landscapes (ancient, modern mining stope, modern mining equipment). Zhang et al. (2011) conducted a case study in Wu'an city of Hebei Province. At present, there is little research on the LEC in mining areas. In the theoretical domain, the landscape spatial structure, ecological attributes and landscape functions have been emphasized, while ignoring ecological processes. In the empirical research domain, most of the study has been focused on high diving coal, semi-humid plains and abandoned mining areas, with a lack of research on open pit mines, especially a lack of LSCPB LEC system construction research. In view of the above problems, the aim of this study is to develop and propose an LEC system suitable for the LSCPB in the SASR. Specifically, the purpose and significance of this study are: (1) a framework of LEC based on multiple factors such as natural ecology, human disturbance and social economy will establish; (2) the constructed classification system can provide theoretical support for the landscape ecological management and planning of semi-arid steppe mining area; (3) provide a theoretical reference for the study of LEC in grassland or other areas; (4) provide the theoretical basis for the research of landscape ecological field in the mining areas, especially the semi-arid steppe mining areas; (5)the constructed classification system will be tested by open-pit and shaft mine LSCPB of Eastern Inner Mongolia.

## 2. Methods

Mining areas is a time and space scales of continuous human activities and strongly disturbed regions. The LEC of LSCPB is a classification based on coal mining and power development as the dominant landscapes, the occurrence mechanism, ecological processes, basic theory, classification principle of its landscape ecological are different from the general countryside, city and wetland landscapes.

### 2.1 Landscape ecological analysis of LSCPB in SASR

The LEC of LSCPB is the result of abstracting the whole attributes and characteristics of complex coal mining and electric power development systems, and is a rational simplification perspective process. Based on understanding of the occurrence and formation process of coal mining and power development, the analysis of the landscape ecological types of LSCPB is the premise of studying the LEC of LSCPB.

Due to the uneven distribution of resources in China, coal resources are mainly distributed in the western and northern regions, whereas energy demand is distributed in the eastern and southern regions. Large-scale, long-distance coal transportation has seriously increased manpower, material, financial and environmental costs. Converting transportation coal into transportation power is an effective way to solve this contradiction by building the LSCPB. The idea of a coal-power base refers to the integration of coal reserves and production, with a planned construction of power plants for external transmission (Zhou et al. 2014). Therefore, the LSCPB is an area of strong human disturbance landscape ecology dominated by coal mining and electric power development.

There are two main types of coal mining: shaft mining and open-pit mining. The method of mining coal by underground excavation is called shaft mining. Open pit mining refers to the method of mining the mineral resources directly after the overlying soil and rock are removed (Du et al. 2014). In the process of open pit coal mining, the types of landscape are as follows: the excavation type of landscape, the type of the occupied landscape, the type of piled up landscape and the types of the undisturbed landscape (Cao et al. 2006). The type of excavation is the large-scale mining pit formed by stripping the surface soil, the overburden or the middle layer of the coal seam during the mining process to obtain the underground coal resources (Fig. 1a). The type of the occupied landscape mainly refers to the dump which is used for stacking the stripped substance in the open-pit mine. The interior of the dump will pile up gangue, weathered rock and soil, hard rock and mixed rock and soil, the surface of which will be covered with a certain thickness of humus topsoil to grow vegetation. In the early stages of exploitation, the stripping material will be stacked outside the open pit mining limit, called the external dump (Fig. 1c). When the large mining pit is formed, the strip will be backfilled within the open pit mining limit, which is called the internal dump (Fig. 1b). The type of the occupied landscape includes the coal preparation plant, coal washing plant, coal transportation corridor(Fig. 1f), railways, all kinds of roads, industrial square, built (structure) buildings, pipelines and transmission lines, all of which are for coal development services.

The landscape types formed during the process exploitation by shaft mining include: (1)mining facilities construction land landscape, mainly used for coal mining, screening and transportation and other constructed sites, such as the mine, coal preparation plant, coal transportation corridor[Fig. 1(f)] and so on; (2) mining office construction land landscape (Fig. 1e), mainly used for coal mine staff office and living places, such as office buildings, canteen, workers' village, dormitory buildings, hall and so on; (3) the mining disturbance landscape is formed by high intensity interference from coal mining, which mainly refers to the subsidence land (Fig. 1h)and ground fissures (Fig. 1g); (4) the type of the occupied landscape refers to the mining of solid mine waste discharge and abandoned land, mainly coal gangue dumps (Fig. 1j).

For the closure of the mine, the areas are generally reclaimed for agricultural land, gardens, woodland, construction land, livestock land, aquaculture land or mine park. According to the "China National Mine Park Construction Work Guide" (Geological Environment Department of the Ministry of National Land and Resources, 2007)the relict mining landscapes are divided into five categories: mineral geological relics, mining production relics, mining relics for social life, mining products and mineral development literature history.

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Thermal power plant landscapes (Fig 1d) mainly include: (1) coal transportation corridor, road or railway; (2) construction land inside the thermal power plant including office space, raw coal hopper, coal mill, rowder coal bunker, boiler, steam turbine, generator, chimney, condensing tower, transformer and so on. (3) high voltage transmission network, (4) coal fly ash dumps formed from coal combustion (Fig. 1i).


(a) (b)

(c) (d)

(e) (f)

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(g) (h)

(i) (j)

Figure 1. Large-Scale Coal-Power Base in Semi-Arid Steppe Region

(a)Open Pit Mine; (b)Internal Dump; (c)External Dump; (d)Thermal Power Plant; (e)Shaft Mine Industrial Square; (f)Coal Transportation Corridor; (g)Ground Fissure; (h)Subsidence Land; (i)Coal Fly Ash Dumps; (j) Coal Gangue Dumps.

2.2 Theoretical basis of LSCPB LEC

The theory, principle and method of LEC of LSCPB are the macroscopic theoretical basis of establishing a scientific, perfect and practical mining landscape classification system, mainly including hierarchy theory, scale theory, landscape processes, the patch-corridor-matrix model, the network, the theory of multiple planning integration and the principle of remote sensing.

2.2.1 Hierarchy theory

Hierarchical theory applies to complex system structure, function and dynamics (Wu 2000). Any biological system has a hierarchical structure. LSCPB is a complex and orderly system structure composed of several units. Complex systems often have hierarchical forms. A complex system consists of interrelated sub-systems, which are made up of their own sub-systems, and so on until the lowest level (Simon, H.A., 1962). High-level classification requires a broad and comprehensive generalization. Low-level classification needs to determine the differences between small-scale landscape units, and can fully highlight the characteristics of each landscape element. In an LSCPB landscape ecological gradation with non-nested characteristics, for example, mining and non-mining areas both have construction land landscapes. The hierarchical system has a vertical structure and horizontal structure. For example, the "Mining Landscape → Mining Construction Land Landscape → Thermal Power Plant Construction Land" belongs to the vertical structure, "Mineral Geological Relics - Mining Production Relics - Mining Relics for Social Life" belongs to the horizontal structure.

2.2.2 Scale Theory

The time and space scales are included in the ecological processed of any landscape (Wiens, J.A., 1989). At different time scales and spatial scales, the same landscape will show homogeneity and heterogeneity at the same time. The level of landscape ecology and the level of hierarchy are also dependent on the size of the spatial scale, so the study of LEC must take into account the role of scale. Ecological scale has three aspects: dimension, category and composition. The dimensions include time scales, spatial scales, and organizational scales. For LSCPB, the time scale can take into account the whole life cycle of the mining area, the space scale is coal-power base, and the organization scale is the landscape scale.

### 2.2.3 Landscape processes

Landscape processes are within the scope of the time and space scales, operating in the landscape, showing the interrelated, interdependent interactions among the landscape elements, emphasizing the occurrence and development of events or phenomena, and are important in affecting the variation of landscape pattern. Landscape-scale processes are driven by many elements and are associated with other processes in more restricted areas. The overall landscape process is the result of the interaction of both natural and man-made factors, and with economic development, technological progress and population growth, the influence of human factors is getting bigger and bigger(Yu 2006). In the prehistoric period, primitive human beings lived on the grassland by hunting, survived equally with other animals, and were not the dominant species that affected the landscape ecology of the area. With the development of human civilization and its productive forces, humans learned to domesticate grazing animals, and the nomadic people were born. Commodity trading and political demand increased as urban landscapes continued to grow and develop in the grasslands. By the late 18th century, the industrial revolution made coal the most extensively used industrial production fuel, and mining landscapes were born.

### 2.2.4 Patch-corridor-matrix model

Patch-corridor-matrix landscape spatial mosaic pattern laid the foundation for the study of the combination of landscape areas of LSCPB. The matrix is the most widely distributed background structure in the landscape. The SASR coal-power base is added to the native grassland as the matrix. The introduction of an artificial patch into the grassland matrix formed the urban landscape patch, and the urban landscape patch originated from the human nature of the natural ecosystem. The obvious features are: (1) the ecological structure in the settlements depends on the biological type that replaces the natural ecosystem. (2) the persistence of highly humanized settlements depends partly on the extent and permanence of human management. The mining landscape is a disturbance patch formed by high intensity disturbance over a period of time, which is different from the matrix of grassland and urban landscape (Zhang 2014). The urban landscape patch and the mining landscape patch are different from the grassland matrix in appearance or nature, and have some internal heterogeneity. In addition, LSCPB of SASR has rivers and other environmental resources corridors, coal transportation corridor and other disturbance corridors, natural grasslands remaining along railways and other remnant corridors, shelters and other planting corridors. On the one hand, corridors are the channels for the transmission and migration of energy, matter and species, while on the other hand, are obstacles for the movement of species in the grassland matrix. So it is necessary to set up a passage through the corridors for these species (Fig. 1f).

### 2.2.5 Network

Corridors intersect each other to form a network that complicates the interaction of corridors with patches and matrix. The function of the network is similar to the corridor, but it is more extensive and close to the matrix. The landscape ecological network connects the different landscape components effectively, serving as a rapid channel of material flow, energy flow and information flow. In the mining landscape, a variety of road networks, railway networks, water networks, and high-voltage power grid networks may be arranged in a crisscross pattern, these networks may have similarities in structure, and are closely linked with the mining landscape patches, but the function is very different.

2.2.6 Theory of multiple planning integration

The particularity of the LEC in the mining area, as reflected in the characteristics of the dynamic nature of mining development should be considered fully, that is, in the classification, not only the current stable subsidence land, coal gangue dumps, coal fly ash dumps, open-pit mine and dumping site and other landscape patch types, but also the landscape patch types that will soon form in the near future, should be considered. Mining landscapes are different from closed systems, and their ecosystems are always open. Due to the constant input and output of material flow, energy flow, information flow and so on, the boundary of the internal patch in the mining landscape has always changed. So we should consider the US Geological Survey land cover classification system (Anderson et al. 1976), the second national land survey technical regulations, urban land classification and land use standards for planning and construction, land use planning, mineral resources planning, reclamation planning for mining areas, mine environmental protection and comprehensive treatment plans and other planning or programs.

2.2.7 Principle of remote sensing

Because of its multi-platform, multi-band, multi-field, multi-phase, multi-angle and multi-polarization characteristics, remote sensing technology has gradually become the main means of LEC mapping. Remote sensing images with various degrees of spatial resolution can be used to classify different levels of landscape ecology. The spectral characteristics of different landscape components are different, so there is a best band for each study. The quantitative study of landscape characteristics and their ecological processes can be carried out by means of obtaining surface parameters by using remote sensing data. Therefore, quantitative remote sensing can further assist the mining LEC mapping, in order to enhance the precision and accuracy.

2.3 Principles of LEC in mining area

Through the analysis of landscape ecology of LSCPB in SASR, combined with the relevant fundamental theories of LEC. The following operational principles of LEC for LSCPB in SASR are put forward:

2.3.1 Comprehensive principle

The LSCPB is a regional synthesis composed of various landscape elements; the formation of the landscape is the result of the combined effect of a variety of factors, and thus classification should reflect the characteristics of the complex. Comprehensive inspection can be conducted from the landscape ecosystem spatial form, spatial heterogeneity combination, occurrence processes and ecological functions of the four aspects of the characteristics. A study of the LEC of LSCPB must take into account all the factors that affect the formation of the landscape. Only in this way can we have a macro grasp of the landscape ecology in the study area, avoid the omission of some landscape elements, and cause an unreasonable construction of the classification system.

2.3.2 Principle of the combination of structure and function

Structure is the basis of function, function is the reflection of structure. The LSCPB landscape ecosystem is composed of multiple interrelated elements, mutual restrained, with an orderly internal structure of the complex geography. The LEC includes unit determination and type merging. The unit determination is based on the functional relationships, and type merging takes the spatial form as the index. LEC is actually focused on the function that inheres to the structure, to divide landscape ecosystem types. Through the establishment of the classification system, we fully reflect the spatial differentiation and organizational association of certain regional landscapes, thereby revealing its spatial structure and ecological function.

2.3.3 Principle of the combination of human dominated and natural landscape

High-intensity mining and power development of coal are the main factors in the change associated with the coal-power base, which has a profound impact on the natural landscape, and the urban landscape affects the grassland matrix in a similar way. For millions of years, there has been almost no type of landscape that is completely unaffected by human activities in the SASR. Therefore, the LEC of LSCPB must adhere to the principle of human dominance. In addition, the landscape is a regional complex synthesis of the regional natural environment and human social interference; its formation and development factors are complex and diverse, while vegetation and hydrology and other natural elements can directly reflect the different characteristics of different types of landscape, they are important indicators for the classification of landscape ecosystem types (Fu et al. 2001). Human dominance is mainly embodied in the functional classification of the landscape, and the natural representation is mainly embodied in the structural classification of the landscape. The division of landscape ecological types of LSCPB in SASR needs to follow the principle of the combination of human dominated and natural landscapes.

2.3.4 Principle of emphasis

The classification of landscape ecological types provides a tool for subsequent analysis and simulation of landscape pattern evolution, landscape ecological planning and evaluation. Even for the study of the same area of landscape ecology, for different research purposes, the focus of research is very different, which will lead to different classification results, Therefore, landscape ecology classification needs to highlight the research focus. For example, in the study of urban landscape ecology, LSCPB can only be used as a part of the industrial and mining storage landscape, but in this study, the mining landscape is the most important. In addition, we should pay attention to the process of the influence of the LSCPB on the regional landscape ecology, and take the human activities and the interference factors into account

2.3.5 Principle of combining qualitative analysis with quantitative research

Qualitative analysis can have a macroscopic grasp and understanding of the landscape ecology of LSCPB, and determine its landscape composition and structure. Qualitative analysis is the basis and prerequisite for quantitative analysis. Quantitative analysis can clearly put forward the boundaries of LSCPB of landscape types, to quantify the large coal base landscape indices, with qualitative and quantitative approaches combining and learning from each other, resulting in the flexibility needed use in order to obtain the best classification results.

## 3. Results

Based on the theory and methodology of landscape classification as the basic principle, following the LSCPB of LEC principle, on the basis of occurrence method land classification, fully considering the ecological attributes of the land, integration patterns, processes and functional theory of landscape ecology, the LEC system of the LSCPB in the SASR has been constructed by using a top-down decomposition classification method. According to the hierarchical nomenclature of biological classification, the four levels of landscape ecology classification of this study are named landscape Kingdom, landscape Class, landscape Family and landscape species. Species in order of increasing specificity. The levels include 4, 20, 67, and more than 200 landscape types, respectively.

Landscape Kingdom: According to the interference process of humans in the natural matrix landscape and the functions of the patches formed after the disturbance, the LSCPB in the SASR is divided into grassland landscape, mining landscape, town landscape and network landscape. Grassland landscape is a natural or semi-natural matrix landscape, with less human disturbance, maintaining the natural condition, mainly used for animal husbandry and agriculture. Its function is primarily biological production and environmental services. The urban landscape is a residential area with a certain scale of industry and commerce, its main function is cultural support. The mining landscape is based on the development of mineral resources as the main function of the region. Generally speaking, the mining landscape belongs to the industrial and mining storage landscape in the urban landscape, but for the purposes and needs of this study, it is upgraded to one of the primary landscapes. The network landscape is a fast channel of material flow, energy flow and information flow, connected by corridors and nodes.

Landscape Class: According to the status of land cover, land use and landscape processes in the landscape area, the two levels were classified. The mining landscape, includes open-pit landscape, inner dumping landscape, the external dumping landscape, mining construction land landscape, mining relics landscape, and mining disturbance landscape introduced previously in section 2.1. The town landscape includes town construction land landscape, industrial and storage land landscape, greenbelt landscape and under construction landscape in town. The grassland landscape includes grassland landscape, farmland landscape, garden landscape, forest landscape, wetland landscape, degraded landscape of agricultural and livestock husbandry. The grassland landscape is the matrix landscape of the study area, based on the natural formation, and provides a variety of primary products. The degraded landscape of agricultural and livestock husbandry which is caused by over utilization of human being and deterioration the of natural environment is a kind of landscape type formed by the degradation of grassland matrix. Networks include those formed naturally, such as water networks, as well as constructed networks such as road, railways and power grids.

Landscape Family and Species: Landscape Family and Species are respectively more specific divisions of the upper classification levels. In order to highlight the impact of coal resource exploitation on regional landscape ecology and the needs of a series of subsequent research work on the evolution, simulation, planning and restoration of the mining landscape, it is necessary to take full account of the various ecological effects brought by coal resource exploitation. For example, changes in topography caused by coal mining will lead to changes in land ecology, which will affect and influence the evolution of the landscape. In order to analyze the direct impact of resource development disturbance on the landscape, terrain changes (slope, etc.) can be included in the classification system as a classification of the signs, such as the open-pit landscape is divided into open-pit-slope and open-pit-flat. In addition, it is necessary to set up the unique landscape types of LSCPB, such as coal gangue dumps, coal gangue dumps, subsided land, ground fissure, thermal power plant and so on. Landscape Family and Species are the basic units of classification, and it is also a unit using high-resolution remote sensing image mapping. It is mainly applied to small-scale landscape classification, which can be combined with digital elevation model and field investigation.

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Table 1. Landscape Ecological Classification System of Large-Scale Coal-Power Base in the Semi-Arid Steppe Region

| Landscape Kingdom | Landscape Class | Landscape Family | Landscape Species |
|---|---|---|---|
| Mining Landscape | Open-Pit Landscape | Open-Pit-Slope Landscape | Working Face/ Non-Working Face-Slope |
| | | Open-Pit-Flat Disk Landscape | Working Face/ Non-working Face-Flat Disk |
| | Internal Dumping Landscape | Internal Dumping Vegetation-covered Area Landscape | Dense/ middle /Low-Vegetation-covered Area |
| | | Internal Dumping Non Vegetation-Covered Area Landscape | Road/Non-Road |
| | External Dumping Landscape | External Dumping Slope Landscape | Vegetation-Covered Area / Non Vegetation-Covered Area |
| | | External Dumping Platform Landscape | Vegetation-covered Area / Non Vegetation-covered Area |
| | | Stacking Outside Dumping Landscape | Vegetation-Covered Area / Non Vegetation-Covered Area |
| | Mining Construction Land Landscape | Thermal Power Plant Construction Land Landscape | Road/ Office Space / Raw Coal Hopper/ Coal Mill / Powder Coal Bunker / Boiler / Steam Turbine / Generator / Chimney /Condensing Tower/Transformer Etc. |
| | | Mining Facilities Construction Land Landscape | Mine/ Coal Preparation Plant/ Coal Transportation Corridor Etc. |
| | | Mining Office Construction Land Landscape | Road/ Office Building/ Canteen/ Workers Village/ Dormitory Building/ Hall Etc. |
| | | Mineral | Typical Deposit and Its Geological |

| | | | |
|---|---|---|---|
| | Mining Relics Landscape | Geological Relics Landscape | Profile / Prospecting Criteria and Flags / Mining Space Relics / Landform and Geological Landscape / Geological Environment Change and the Geological Disaster Relics |
| | | Mining Production Relics Landscape | Exploration Relics /Mining Relics /Beneficiation Relics /Smelting Processing Relics |
| | | Mining Relics for Social Life Landscape | Site of Social Life and Belief Activities Place or Relics / Miners Clothing and Articles Remains / Social Customs Remains /Institutions, Facilities, Equipment and Related Remains of Social Management or Relics |
| | Mining Disturbance Landscape | Mining Waste Bare Landscape | Pollution-free/ Contaminated |
| | | Subsided Land Landscape | Stable Subsidence / Unstable Subsidence |
| | | Ground Fissure Landscape | Stable / Unstable |
| | | Coal Fly Ash Dumps Landscape | Bead Particle / Slag Particle |
| | | Coal Gangue Dumps Landscape | Stop Stacking Gangue Dumps / Stacking Gangue Dumps |
| **Town Landscape** | Town Construction Land Landscape | Town Residential Areas Construction Land Landscape | Urban/ Township /Country / Village Residential Areas Construction Land |
| | | Business Service Construction Land Landscape | Commercial Land / Business Affairs Land / Recreation and Sports Land/Public Facilities Outlets Land /Other Business Service land |
| | | Public Management and Public Service Construction Land | Administration /Culture/Education/ Sports/ Sanitary Construction Land Etc. |

| | | | |
|---|---|---|---|
| | | Landscape | |
| | | Reconstruction Land of Mining Area Landscape | Reconstruction Residential Areas/ Business Service/ Public Management and Public Service / Special Land of Mining Area |
| | | Special Construction Land Landscape | Military Affairs /Security Land |
| | Industrial and Storage Land Landscape | Industrial Land Landscape | A/B/C Class Industrial Land |
| | | Reconstruction Industrial Land of Mining Area Landscape | Reconstruction Industrial, Storage and Surface Pipeline Transportation Land of Mining Area |
| | | Storage Land Landscape | Commonly / Special Storage Land |
| | | Surface Pipeline Transportation Land Landscape | Oil and Natural Gas Etc. Surface Pipeline Transport Land and Affiliated Facilities |
| | Greenbelt Landscape | Park Greenbelt Landscape | Comprehensive Park / Community Park / Theme park / Belt Park / Other Park Greenbelt |
| | | Reconstruction Greenbelt of Mining Area Landscape | Reconstruction Park /Public/ Production Greenbelt Etc. |
| | | Road Greenbelt Landscape | Road Green Belt / Traffic Island Greenbelt / Parking Greenbelt/Other Road Greenbelt |
| | | Residential Areas and Units Attached Greenbelt Landscape | Residential Areas / Units Attached Greenbelt |
| | | Production and Defense Greenbelts Landscape | Pure Productive Greenbelts / Comprehensive Production Greenbelts/ Urban Shelterbelt / Sanitary Isolation Belt / Safety Shelterbelt / Urban High Pressure Corridor Green Belt /City Group Isolation Belt Etc. |

| | | | |
|---|---|---|---|
| | | Public Greenbelt Landscape | Small Garden / Group Greenbelt / Other Public Greenbelt |
| | Under Construction Landscape in Town | Idle Hardened Ground in Town Landscape | Idle Road /Abandoned Square Etc. |
| | | Construction and Demolition Site Landscape | Construction/Demolition Site |
| **Grassland Landscape** | Grassland Landscape | Natural Pasture Landscape | Caragana Microphylla / Stipa Grandis + Leymus Chinensis / Leymus Chinensis / Stipa krylovii Roshev + Leymus Chinensis / One or two year cluster / Stipa krylovii Roshev / Splendid Achnatherum + Leymus Chinensis / Splendid Achnatherum/ Stipa Grandis Etc. |
| | | Improved Grassland Landscape | High / Moderate/ Low-Vegetation Cover |
| | | Artificial Herbage Land Landscape | High / Moderate/ Low-Vegetation Cover |
| | | Reclaimed Grassland of Mining Area Landscape | High / Moderate/ Low-Vegetation Cover |
| | | Other Grassland Landscape | High / Moderate/ Low-Vegetation Cover |
| | Farmland Landscape | Dry Land Landscape | Corn/Soybean/ Wheat/Naked Oats/ Potato/ Flax/Hill Potherb /Beet/Mixed Beans/Carrot and Other Dry Land |
| | | Irrigation Land Landscape | Paddy Field Etc. |
| | | Reclaimed Farmland of the Mining Area Landscape | Reclaimed Dry Land/ Irrigation Land /Vegetable Greenhouse Etc. |
| | | Vegetable Greenhouse Landscape | Simple Greenhouse / Arched Steel Tube Vegetable Greenhouse / Solar Greenhouse / The Steel Structure of |

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|---|---|---|---|
| | | | Multi Span Greenhouse / High-Grade Multi-Span Stripping Vegetable Greenhouse |
| | Garden Landscape | Reclaimed Garden of the Mining Area Landscape | Reclaimed Hazelnut/ Blueberry/ Watermelon/ Sunflower/Chinese Medicinal Herb Garden Etc. |
| | | Orchard Landscape | Hazelnut/ Blueberry/ Watermelon Garden Etc. |
| | | Other Garden Landscape | Sunflower/Chinese Medicinal Herb Garden Etc. |
| | Forest Landscape | Natural Forestland Landscape | Quercus Mongolica Forest/ Birch Forest / Aspen Grove / Pinus Sylvestris Forest /Valley Forest Etc. |
| | | Artificial Forestland Landscape | Artificial Pinus Tabulaeformis/Nursery Etc. |
| | | Reclaimed Forestland of the Mining Area Landscape | Reclaimed Artificial Pinus Tabulaeformis/Nursery Etc. |
| | Wetland Landscape | Natural Wetland Landscape | Riverine/ Lake/Marsh Etc. |
| | | Constructed wetland Landscape | Reservoir/Urban Artificial Landscape/Excavating or Collapse Wetland |
| | Degraded Landscape of Agricultural and Livestock Husbandry | Saline Land Landscape | Mild/Moderate/Severe Saline Land |
| | | Desertification Landscape | Mild/Moderate/Severe Desertification Land |
| | | Bare Rock Landscape | Human Disturbance/ Natural Degraded Bare Rock |
| | | Bare Land Landscape | Human Disturbance/ Natural Degraded Bare Land |
| **Network landscape** | Water Landscape | Graff Landscape | Natural River/Artificial Channel |
| | | Lake Landscape | Natural Lake/Artificial Reservoir |
| | | Swag Landscape | Natural/ Artificial Swag |
| | Railway Landscape | Special Railway of Mining | Special Railway of Mining |

| | | | |
|---|---|---|---|
| | | Landscape | |
| | | Other Railway Landscape | National/ Local/Joint-Venture Railway Etc. |
| | Road Network Landscape | Special Road of Mining Landscape | Paved/ Non-Paved Special Road of Mining |
| | | Highway Landscape | Expressway/First /Second /Third /Fourth Class Highway |
| | | Urban Road Landscape | Expressway/Main/Subsidiary/Branch Road |
| | | Country Road Landscape | Paved/ Non-Paved Country Road |
| | Power Network Landscape | Transmission Network of Coal-Power Bases Landscape | Ultra-High /Super-High/High/ Medium Voltage Grid |
| | | Other Transmission Network Landscape | Ultra-High /Super-High/High/ Medium Voltage Grid |

## 4. Case study

4.1 Overview of the study area

Eastern Inner Mongolia includes Hulunbeier City, Xing'an League, Tongliao City, Chifeng City, Xilin Gol League 5 League or city in the eastern part of Inner Mongolia. The region is in the eastern part of the Eurasian Continental steppes, with a total area of 664,900 square kilometers. Eastern Inner Mongolia has a temperate, semi-arid continental monsoon climate, arid in the spring, with short warm summers, early autumn frosts, and cold winters.

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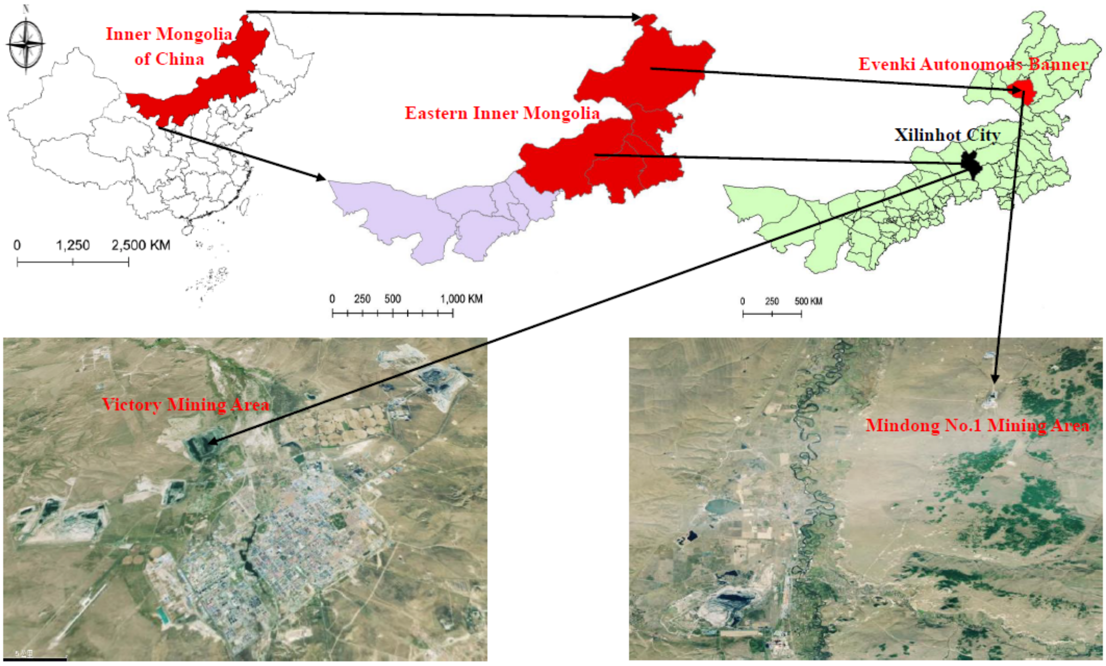


Figure 2. Location of the Study Area

4.2 LEC mapping

On the basis of the LEC system of LSCPB, additional LEC mapping is an important part of the research in the area. The mapping can be used to visualize the performance of landscape classification results, to comprehensively reflect the interrelationship among landscape elements, and reflect the spatial distribution of landscape elements, and to further test and evaluate the validity of the classification system. Based on the remote sensing data of Landsat 8, Resource No. 1 and Resource No. 3 in 2015 and 2016, the LEC system of LSCPB in SASR constructed by this paper is combined with supervised classification, visual interpretation and field investigation, respectively, to map the landscape Kingdom, Class, Family of the Victory and Mindong No.1 mining areas. Data sources are shown in Table 2, and the remote sensing image after classification is shown in Fig. 3.

Table 2. The Victory and Mindong No.1 Mining Area LEC Data Source

| Mine / Grade | Victory Mining Area | | | Mindong No.1 Mining Area | | |
|---|---|---|---|---|---|---|
| **Kingdom** | Landsat8 | 30m*30m | 20161018 | Landsat8 | 30m*30m | 20150705 |
| **Class** | Landsat8 | 30m*30m | 20161018 | Landsat8 | 30m*30m | 20150705 |
| **Family** | Resource No. 1 02C | Panchromatic 5m / Multispectral 10m | 20160923 | Resource No. 3 | Emmetropia Panchromatic 2.1m/ Multispectral 5.8m | 20150810 |

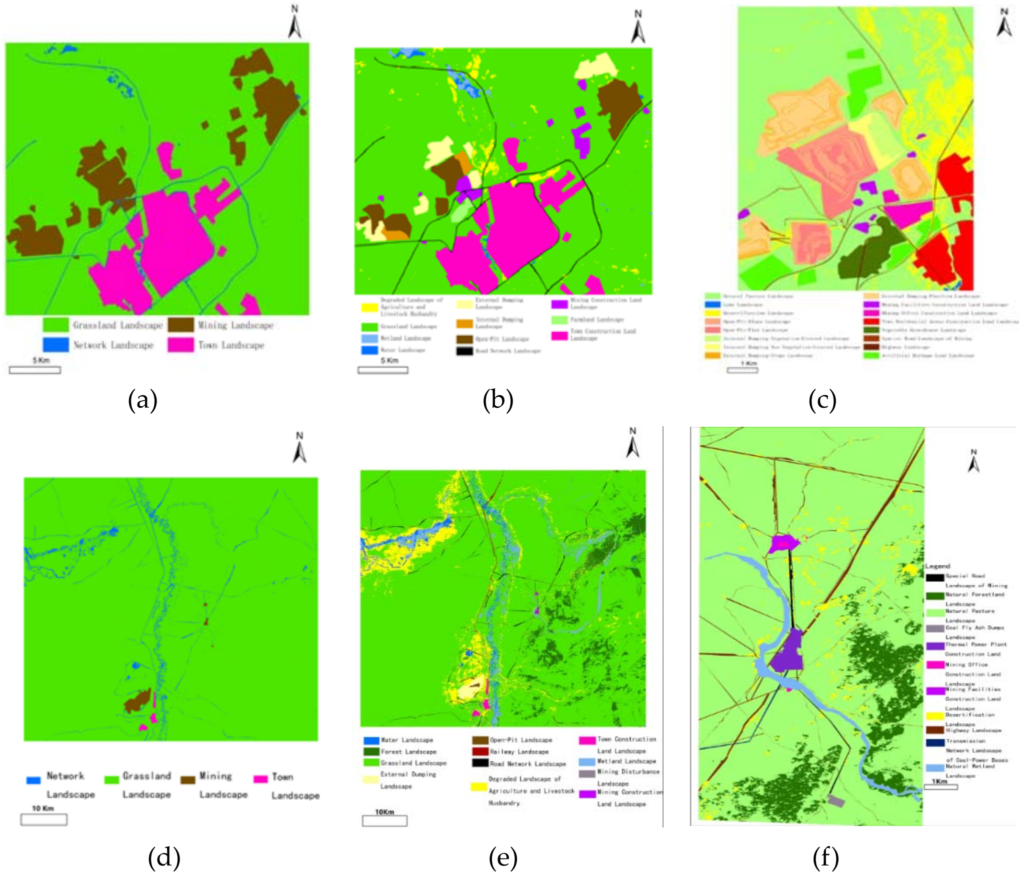


Figure 3. (a)Landscape Kindom of Victory Mining Area; (b) Landscape Class of Victory Mining Area; (c) Landscape Family of Victory Mining Area; (d) Landscape Kindom of Mindong No.1 Mining Area; (e) Landscape Class of Mindong No.1 Mining Area; (f) Landscape Family of Mindong No.1 Mining Area

## 5. Discussion and Conclusions

The SASR of LSCPB is located in the frigid and arid region. The plant growth period is short, the biomass is low, the biological chain is simple, the processes of material circulation and energy conversion in the ecosystem are slow, which makes the regional ecological environment fragile. High-intensity, large-scale coal power development and utilization is considered to be the main cause of landscape ecological change in grassland mining area. Therefore, it is necessary that the basic research on the landscape ecological structure, function and process of the steppe coal-power base under high-intensity mining disturbance is conducted systematically. Research and development for the key technologies of landscape ecological restoration for the coal-power base in the SASR, have important roles in the sustainable development of the coal-power base and regional ecological security. Landscape restoration and reconstruction is for landscape degradation, the landscape degradation from the form of expression can be divided into landscape structure degradation and landscape function degradation (Guan et al. 2003). The objective of ecosystem classification is to reduce the structural and functional complexity of ecosystems in models while quantifying key social and ecological processes involved in shaping current ecosystem conditions (Steenberg et al. 2015). The degradation or restoration of certain key nodes, patches and corridors in the landscape plays a vital role in the sustainable development of regional ecology. The construction of the LEC system can identify these key elements from the large region, and provide top-level guidance for subsequent of landscape ecology research in mining areas.

The LEC system constructed in this study fully considers differences in landscape pattern, function, process and grade. Planning needs a system of classification of the landscape, which is consistent and reflects the natural patterns, the potential capacity and the limits of natural units, and the history of human use (Haase 1989); to some extent is a subjective process. The author hopes that the LEC constructed by this research can provide theoretical support for decision makers, government, engineering construction personnel and other researchers (Wu et al. 2017). Each landscape patch unit is a discrete system generated by grid and geology, geomorphology, soil, vegetation, climate, wildlife, water, man and many other factors (Cullum et al. 2016). Not all landscapes can be (easily) decomposed into a set of structural-functional units that can be clearly and unambiguously delineated and linked to explanatory conceptual models (Cullum et al. 2016). Moreover, any ecosystem is a complex system that is constantly changing, and the ecological attributes and boundaries of any landscape patches have the potential for change, and may even produce new landscape types. Therefore, the dynamic changes of regional landscapes should be taken into full consideration, and the study of LEC needs to be improved and adjusted constantly.

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