Evaluation of the Reclamation Suitability of Industrial and Mining Wasteland

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Abstract To evaluate the reclamation suitability of industrial and mining wasteland is the premise of reclamation. The wasteland was firstly categorized according to land use status and damage types. Then the evaluation process of reclamation suitability was introduced, which involves two steps, the first step was to exclude those unsuitable wasteland by the limits conditions, while the second step was to evaluate the suitability degree of those suitable wasteland. From the perspectives of soil fertility, soil pollution, farmland water conservancy and land damage, twelve evaluation factors, including soil depth, gravel content, bulk density, organic material content, pollution index, gradient, flatness, irrigation and drainage condition, source of borrowed earth, distance from the residential settlement, erosion modulus and damage extent, were selected to establish an index system for evaluating the abandoned industrial and mining land, aiming to provide references for the future reclamation of industrial and mining wasteland.

Key words Industrial and mining wasteland, Reclaimed farmland, Suitability, Evaluation

1 Introduction

The industrial and mining wasteland refers to the land destroyed by the construction of road, railway, water conservancy, the establishment of mining, electric, chemical and oil industry enterprises, activities of mining, quarry mining, sand collecting and brick making, which can not be used without reclamation. For a long time, the land and mineral resources have contributed a lot to the development of China, but have caused great damages to the lands at the same time. According to the survey, about 20 million mu lands have been destroyed by mining activities during 1987 - 2009, if we count as per 20% reclamation rate, there will be 16 million mu lands to be reclaimed[1]. In the premise of improving the mining environment, the reclaimed mining wasteland was linked with the new construction land to reasonably revitalize and adjust the construction land, so as to ensure that the total amount of construction land maintains at the original level, the area of farmlands would not be decreased and land quality gets improved.

The evaluation of reclamation suitability is the premise and foundation of land reclamation programs and provides a scientific basis for the reasonable reclamation and utilization of land resources. After a long-term practice of research, Bai Zhongke evaluated the reclamation suitability of a large opencast coal, which involved both the reclaimed and non-reclaimed wasteland, providing useful experience for the reclamation of local mining lands[2]. Through fields visits, Su Guangquan classified and then evaluated the total abandoned mining land in China, which provided technical references for the reclamation of abandoned land resources[3]. The reclamation evaluation of industrial and mining wasteland is an important part of the whole reclamation process, it is not only a summary of the previous investigation of industrial and mining wasteland as well as the analysis of their future reclamation potential, but also a reference for the inspection of farmland quantity and quality after reclamation. In this paper, the reclamation suitability of industrial and mining wasteland was discussed, aiming to provide references for the land rehabilitation in the future.

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2 Progress of suitability evaluation

In accordance with the general land use plan and relevant programs, the suitability evaluation of industrial and mining land reclamation is a process to evaluate the suitability of reclaiming the mining land into farmlands which is carried out based on the original land use types, land damages, soil conditions, *etc.* under reasonable technical and economic conditions, and it reflects the general trend of land stability and productivity.

2.1 Classification of evaluation units The evaluation unit is not only the smallest spatial unit of suitability evaluation and classification, but also the objective basis of field survey. The classification of evaluation units directly decides the size of evaluation workload, the accuracy of evaluation results and the applicability of evaluation achievements[4]. At present, there are three methods to classify the evaluation units: (1) the classification of soil genesis, namely, to classify as per the requirement of geotechnical property, geotechnical proportion, method of abandonment, stacking morphology, conservation of soil and water, environment protection and land Claymation[2,5]; (2) land types, which means to classify the lands into the types of farmland, woodland, grassland, garden land, *etc.* based on the national land use classification standard as well as the land utilization conditions and land cover characteristics; (3) types of land damage, which means to classify the lands into the types of open-pit, tailing pond, spoilbank,

surface subsidence area, topsoil stockpiling area, *etc.* according to their types of damage. The author believes that the above methods all have their advantages and disadvantages. From the author's point of view, in the premise of a detailed investigation on the land resources in the mining area, the basic evaluation units were determined according to the existing land use types and land use characteristics as well as the destroy of land by mining. With the land use state as the basis for the first-level classification, the land state was categorized into three stages of original geomorphy, destroy and reclamation. Since the study in this paper focuses on the abandoned industrial and mining land, it only needs to determine the lands at the second stage of damage and to explore their land damage types in order to distinguish the difference among cover, destroy and subsidence. With the land use state as the basis for the second-level classification, the lands in the mining area were classified into different types according to the land classification in 2007 Classification and the practical land use status in the mining area. Therefore, the author determined the suitability evaluation unit as per the actual land use status in mining area, which could be referred to in Table 1.

Table 1 Land use classification of the industrial and mining wasteland

Phase	Types	Land types
Phase of damage	Subside	Farmland
		Woodland
		Grassland
	Digging	Opencast stope
		Borrow earth pits
	Pressing	Spoilband
		Flyash stock
		Tailings pond
		Debris land
		Temporary construction land

2.2 Ideas of suitability evaluation The abandoned industrial and mining land should be evaluated before being reclaimed into farmlands according to the existing standards and related requirements for farmland quality, in order to find out the restricting factors preventing the wasteland from being reclaimed and exclude the wastelands that aren't suitable to be reclaimed by the limits methods, and those suitable wastelands are then generally evaluated based on their quality standards to determine their degree of suitability.

The conditions of soil texture, pollution, surface ground and damage conditions were taken into account when excluding those unsuitable wasteland by limits method. The reasons are as follows: (1) The gravelly soil is hard for the plants to root and for the transport of water and fertilizer, which brings a lot of trouble to normal farming, thus the gravelly soil is obviously not appropriate being used as farmlands. The soil texture can be referred to the standards of "surface soil texture" in *Grading of Farmlands*, the lands which can be used as farmlands are limited to those with the exposure rate of gravelly soil or surface rocks above 25% and the spacing of rocks less than 10 cm; (2) Soil pollution will not only result in a great decline of crop production, but also bring great harms to human health if the polluted crop is transferred to the food chain. According to the third-level conditions in *Soil Quality Standards* as limiting conditions, the soil cannot be reclaimed if its pollutants exceed the third-level standards. (3) The slope of ground can help redistribute the water, temperature and heat, but a great gradient different will influence the normal growth of crops, and make it hard for the crop growth by both manual or mechnical operations. Thus, according to the national policies, the returning of farmlands into forest is limited to the 25° slope; (4) The reclamation suitability of farmlands is evaluated by the pattern and degree of damage, because every type of damage is the composite results of environmental influence[6], generally, the open-pit mining will result in the occupation and pressing of digged and waste earth. For example, the subsided and waterlogged lands are not suitable to be reclaimed into farmlands, while the digged lands are directly classified into the type of severe damage which cannot be reclaimed. The land with even only one of the above four limiting factors exceeding standards can be directly classified into the unsuitable category.

The industrial and mining wastelands which are suitable to be reclaimed into farmlands are firstly screened out by the limits method, and then their suitability degree is evaluated according to the factors of soil fertility, soil pollution, the farmland water conservancy facilities as well as the related technical factors to soil damage degree. An hierarchical evaluation index system should be established to calculate the suitability degree, so as to provide scientific basis for the future evaluation of abandoned mining lands. A flow chart of evaluation process can be seen in Fig. 1.

3 Establishment of the evaluation index system

3.1 Selection of evaluation index

3.1.1 Soil fertility.

(1) Soil depth. The combination of soil layer and loose parent material layer reflects the supportive capacity of soil for the root growth of crops, which directly influence the rooting of plants, as well as the content of water and nutrients in underground root. The depth of covering soil is an important index for reclamation and determines the growth of vegetation.

(2) Gravel content. The content of gravel in soil is closely related to soil aeration, fertilizer maintenance, water retention and the difficulty of farming, and it is an important basis of making the measures for using, managing and improving the soil. In the spoilbank, the content of gravel in soil is greatly different at different sites due to the different sources of covering soil, as well as the process and timing of dumping. However, high content of gravel will cause great difficulty to the rooting of plants and the absorption of water and fertilizer, thus it can be an important factor for evaluating the reclamation suitability of wasteland.

(3) Volume weight. During the processing of mining and transport of mineral resources, the original volume weight of soil has been greatly changed as a result of pressing and digging. The volume weight of soil should also be an important index of evalua-

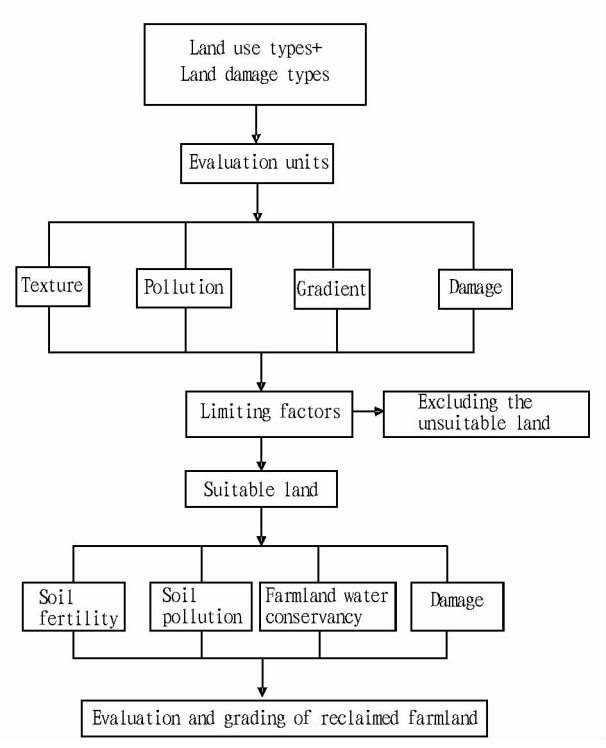

Fig. 1 Flow chart of suitability evaluation for reclaimed farmland

ting the spoilbank, because the volume weight of soil which is repeatedly pressed by heavy machinery enlarges, and will greatly influence the agronomic traits of soil, the surface soil crusting, water penetration, evaporation, runoff and water erosion[7], as well as the growth of plants.

(4) Organic matter. The organic matter in soil is not only an important source of plant nutrients, but also an important factor of soil texture influencing the soil physicochemical property. The organic matter will generate organic acid and humic acid during its decomposition, which helps dissolution and efflorescence of the mineral elements in soil; the organic matter shows complexion and reducibility functions of heavy metals, as well as adsorption of organic pollutants, which will reduce the toxicity of heavy metals and organic pollutants.[8]

3.1.2 Soil pollution.

(5) Pollution index. The toxic and poisonous substance is transported into the soil and destroys its normal ecological function of soil[9,10]. According to the national and industrial standards, the seven elements, including Cd, Cr, Cu, Pb, Zn, As and Hg, are selected as the indexes to evaluate the composite pollution of soil by the single factor pollution index and Nemerow index[11,12], and then the soil cleanliness is determined by the size of pollution index value P.

3.1.3 Farmland water conservancy.

(6) Slope. The slope of land can redistribute the precipitation and heat, which, to some degree, reflects the soil erosion degree as well as the suitability of land to be reclaimed into farmlands.

(7) Ground flatness. The ground flatness means to evaluate the height difference of a patch of land. A great height difference will result in the siltation of water in the center, which is not good for farming.

(8) Irrigation and drainage conditions. The water conservancy conditions of surrounding farmlands directly influence the supply and drainage of water for the growth of crops, which is especially essential for the agricultural development as well as drought and flood prevention. The supported conservancy facilities should be based on the practical conditions of local area.

(9) Source of borrowed soil. The moving distance of earth is closely related to its economic costs. The longer the distance, the higher the costs of transport and labors, and the lower the economic benefits of reclaimed farmlands will be.

(10) Distance from the residential settlement. The distance from the residential settlement, to a certain extent, is related to the farming enthusiasm of neighboring farmlands and reflects the value of reclaimed farmlands.

3.1.4 Status of damage.

(11) Erosion modulus. Erosion modulus refers to the phenomenon of surface soil degradation caused by wind and rainwater erosion. Soil erosion will result in a great loss of organic matter and nutrients in soil, deterioration of soil physicochemical properties, a rapid decline of soil fertility, and great reduction of crops. Apart from the natural wind and rainwater erosion in the mining area, a massive amount of earth is moved during the open-pit mining process, which, as a result, will exacerbate the erosion, wash away the surface soil and even the vegetation, making the farmland into wasteland. Thus, the investigation of soil erosion in the mining area will be beneficial to determining the suitability degree of farmlands.

(12) Damage degree. According to the soil damage types, the soil damage degree was determined. The digged land can be directly graded into the severe degree of damage; the damage degree of subsided and pressed lands are then investigated and determined according to the degree of their subsiding and ground cleave by referring to the experimental and literature data of all related disciplines[13].

3.2 Establishment of evaluation system According to the above-mentioned index, as well as the standards recorded in *Soil Quality*, *Grading of Farmlands*, *Grading of Farmland Types* and *Quality in Whole China*, *Technical Regulations for the Quality Inspection of Farmlands*, *Technical Standards for Land reclamation (Trial)*, *Technical Regulations of the Second National Soil Survey*, and *The Classification Standards for Soil Erosion*, an index system was established for evaluating the reclamation suitability of industrial and mining wastelands, which classifying the suitability degree into four levels (Table 2): the first-level land has high suitability without limitations to be reclaimed into farmlands; the second-level land has medium and high suitability with little limitation; the third-level land has medium suitability with certain limitations; the fourth-level land has medium or low suitability with

obvious limitation. From the pure perspective of land use, the four-level land has the possibility to be reclaimed into farmlands, but requires both high economic and technical costs to be reclaimed, thus it is considered to temporarily reclaim the four-level land into woodland or grassland, and then change it into farmlands when the soil quality gets improved.

Table 2 The index system of suitability evaluation for reclaimed farmland

	First-level	Second-level	Third-level	Fourth-level
Soil depth//cm	>100	60 – 100	30 – 60	<30
Gravel content//%	<1	1 – 3	3 – 5	>5
Volume weight//g/cm^3	1.2 – 1.3	1.3 – 1.4	1.4 – 1.6	>1.6
Content of organic matter//%	>4	2 – 4	0.6 – 2	<0.6
Pollution index	<0.2	0.2 – 0.4	0.4 – 0.7	0.7 – 1
Slope//°	<3	3 – 8	8 – 15	15 – 25
Flatness//cm/hm^2	<5	5 – 10	10 – 20	>20
Irrigation and drainage conditions	Perfect	Basically perfect	Average	None
Source of borrowed earth//km	<0.5	0.5 – 2	2 – 5	>5
Distance from the residential settlement//km	<0.3	0.3 – 0.5	0.5 – 1	>1
Erosion modulus	<1 000	1 000 – 2 500	2 500 – 5 000	>5 000
Damage degree	None	Light	Medium	Severe

3.3 Method of suitability evaluation There are still not unified or fixed method of suitability evaluation till now[14]. Some quantitative mathematical evaluation methods, including the index method, Grey evaluation, fuzzy evaluation, neutral network, and matter element analysis, have been gradually applied and developed[15-17]. The logical and systematic characteristics of various mathematical models will not be analyzed and compared. With the development of spatial technology, the combination of various mathematical models and GIS will effectively improve the accuracy of suitability evaluation and the spatial application of different scales.

4 Discussion

(1) Classification of evaluation units. It include two parts: firstly, the wastelands are categorized according to their different damage types, so as to better determine the land use status in the mining area; secondly, the lands have different natural attributes, such as farmland, woodland and grassland. The classification of evaluation units should take into account the connectivity of reclaimed farmlands, which means to reach a scale level and coordinate with the surrounding landscape.

(2) In terms of the suitability evaluation, one the one hand, those unsuitable lands are firstly excluded by the limiting conditions, on the other hand, those suitable wastelands are reclaimed into farmlands. The existing techniques and method make it possible for generally most industrial and mining wastelands to be reclaimed, but it is not the most efficient to turn the wastelands into farmlands within a short period so far as the reclamation costs are concerned. For example, the pollutants of a seriously polluted land can reduce to an acceptable range after a certain period of efflorescence[18-19], or be transferred to the already polluted land by the means of borrowed earth, but both methods required long time or high costs of earth moving. Thus, under reasonable economic and technical conditions, those wastelands which cannot be reclaimed within a short period at low costs should be excluded.

(3) The establishment of an index system for evaluating the suitability of wasteland reclamation is general. From a strict sense, different regional conditions and landforms, as well as the special conditions of mineral types and mining methods should be taken into account, which requires not only to further screen and add up some indexes, but also to adjust some of the values to adapt to the practical conditions. To evaluate the suitability of wasteland reclamation is not simply to screen out the suitable land, but to classify the suitability degree so as to provide scientific basis and references for the land reclamation.

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(To page 71)

process. The content of organic material is higher than the lower one. The microbiotic crust is an important mater that fixes the sand. The content of organic matter is low, between 0.1 and 2.3 g/kg. Once the surface soil structure and ground vegetation is destroyed, it is easily to cause desertification.

The vegetation in the hinterland of desert is mainly desert plants who can withstand tough weather.

4.5 Determination of final reclamation orientation The project is in northwest China. The natural environment is poor and land use is simple. The destroyed land is sandy land and other grassland. The suitability of reclamation unit is in the fourth level. Considering the actual situation and existed reclamation, the final reclamation is the original ecological sightseeing and sand prevention.

Table 3 Evaluation result of the suitability of reclaimed soil

Evaluation unit	Crops		Forestry		Husbandry	
	Level	Limited factors	Level	Limited factors	Level	Limited factors
Sandy land	Fourth level	Soil and irrigation condition	Fourth level	Soil and irrigation condition	Fourth level	Soil and irrigation condition
Other grassland	Fourth level	Soil and irrigation condition	Fourth level	Soil and irrigation condition	Fourth level	Soil and irrigation condition

5 Conclusions

In response to the fragile ecological environment in the Gurbantunggut desert and the influence of oilfield on land resources, and considering the achievement and mistakes in the reclamation of oilfield in the Gurbantunggut desert, the reclamation of oilfield in the Gurbantunggut desert is concluded as follow.

Firstly, generally speaking, the decision - maker of the oil company should be aware of the environment protection and create a pleasant atmosphere. The land protection should start from scratch. The importance of land reclamation needs to be emphasized so as to make more people aware of environment protection.

Secondly, during the design of oilfield development and actual construction, designers should try to avoid the arbor forest, well field and station as much as possible. While drilling, the penetration of mud should be prevented so as to use green water. The original oil should be processed in time and the polluted soil should be treated by professional companies.

Thirdly, reclamation direction and target should be determined. To recover the original land should be the primary purpose of reclamation. In order to prevent desertification, reed should be planted to solidify the sand and guarantee the coverage.

Fourthly, during the reclamation, various kinds of vegetations should be mixed at corresponding percentage to recover the original vegetation coverage.

Fifthly, the characteristics of natural geology and desert vegetation should be utilized to reinforce the protection of reclamation. The effective protection policy should be built to intensify reclamation. It is feasible to use internet to manage data so as to deal with problems in time.

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(From page 68)

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