Problems and Solutions about Land Use of Different Karst Environments in Southern China

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Abstract This paper is aimed to analyze the current situation and problems about land use of various karst environments via field survey, documentation and comparison methods, and to make reasonable recommendations about land use and management for different karst types in a bid to provide theoretical and practical basis for optimization of karst land use and the comprehensive control of karst rock desertification. The results show that, ① as the bare karst areas are lack of water and soil and highly vulnerable to droughts and floods, land utilization in such areas should follow the principles of soil and water conservation and ecological restoration, emphasize both the ecological benefit and the economic benefits and reasonably configure the land resources to achieve virtuous circle; ② in covered karst areas, the most important task is to take measures to prevent the appearance of secondary karst rock desertification, water exhaustion and karst collapse; ③ the buried karst areas shall mainly focus on prevention of overlaying sand shale collapse, and possible pollution of deep karst water and the surface land resulted from exploration and exploitation of oil and gas and geothermal water. ④The final conclusion is that features and problems of land utilization of the three karst types are different from each other, and that the general principle for land use in karst regions shall be based on the local conditions.

Key words Land use, Types of karst environments, Karst rock desertification, Current situation and problems, Recommendations and solutions

1 Introduction

China is a large karst country, in where the bare, covered and buried karst areas add up to 3.44 million km^2 and the naked carbonate rock areas amount to 907,000 km^2[1]. The bare karst area in southwestern China, in which carbonate rocks are continuously distributed, is one of the three largest karst areas in the world. As a typically ecologically fragile area, the karst area attributes its vulnerability firstly to the low content of Acid – Insoluble Residua and slow soil forming speed, which results in thin soils in most of the areas. Secondly, thin soils, abundant calcium, alkaline and rocky environment restrict the biodiversity. Thirdly, a large number of underground cracks, caves and underground river systems form the ground and underground double space; part of water resources is preserved in the underground space while being lack on the surface; the shortage of water and soil restricts the development of agricultural production. Recently, the accelerating growth of population in some karst areas is intensifying the conflicts between people and land, and worsens the karst environment which is originally fragile. At present, there have been some domestic and oversea researches of land utilization in fragile karst ecological areas. However, such studies are relatively fragmented, there contents mainly focus on the relationships between the land use and karst ecological factors[2,3], the impact of land use on karst groundwater[4], and the influence of land use on soil erosion and rock desertification[5,6], *etc*. Currently, although problems related to land use have been highlighted in some karst areas during economic development and the comprehensive control of karst rock desertification, but specific and detailed guidelines are still scarce and unclear. There is still a lack of systematic studies on problems and countermeasures of land use; there are few corresponding reports and solutions about the relationship between land utilization and the karst environments. Based on a lot of field surveys, this paper analyzes the status, characteristics and problems related to land use in various karst areas and puts forward corresponding principles and directions in a bid to provide the theoretical and practical basis for optimal combination of land use, the comprehensive control project of rock desertification and the new rural construction.

2 Historical reviews on land use in karst areas of southern China

Generally, karst rock desertification in ecologically fragile karst areas results from human disturbance and climate fluctuations. During a short period, the climate is less likely to be volatile and the human disturbance becomes the incentive or direct cause for karst desertification. According to researches, the average annual amount of soil erosion is proved to be relatively small in the karst slopes associated with good vegetation[7]. However, deforestation and subsequent cultivation will lead to rapid expansion of soil erosion; usually, most of the topsoil will be corroded in a decade[8], resulting in the exposure of bedrock. During the survey in Nanchuan County, Chongqing, local people also pointed out that there were a lot of shrubs and *Pinus massoniana* trees in many karst slopes in 1950s. However, the subsequent cutting resulted in intense soil erosion, and now some slopes have been changed as se-

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vere desertification ones, more than 60% of the ground surface is covered with bedrocks. According to researches from Pei Jianguo et al., soil erosion and rock desertification mainly happened after 1960s[9]. Consequently, in bare karst areas, the peak clusters around the karst depressions were covered with lush vegetation before 1960s. In the following 50 years, the land degradation occurred and the desertification happened or has been aggravating due to increasing population and extension of cultivated lands on the karst slopes.

Covered karst environments, which are mainly covered with overlying soils, are always distributed in the karst depressions and basins, such as Huaihua basin, Hunan province, Xiushan basin, Chongqing, *etc*. In recent times, the accelerated urbanization process and land development have been destroying the overlying soils and vegetation, resulting in the occurrence of rock desertification and soil erosion, karst collapse, decrease or even disappearance of karst springs flow, *etc*.. Buried karst areas are covered with non-soluble rocks and have good land utilization conditions. The representative of such areas is Sichuan basin, where the deep karst spaces are reserve space for oil, gas and spring water. However, the land use has currently been intensified, underground oil and gas exploration and exploitation, tunnel construction, *etc*. developed rapidly.

3 Problems and solutions for land use in bare karst environments

Bare karst environment is the largest area in karst regions of southern China (Fig. 1). Fig. 2 shows the three most common types of bare karst environments, Fig. 2a is a typical type of countertrend slope whose slope aspect is opposite to the rock tendency. Such slopes can be seen in Dongsheng village, Nanchuan district, Chongqing municipality; Fig. 2b shows the dip slope whose slope aspect is consistent with the rock tendency and which can be seen in Youyang county, Chongqing, GuihuaWuji village, Nanchuan county, *etc*; Fig 2c shows the peak cluster-depressions, Guizhou – Guangxi border and Guilin basin, Guangxi autonomous region are most common examples of this type. In addition, some long and narrow bare karst landscapes often stretch along axis of anticlines in paralleled ridge – valleys of east Sichuan.

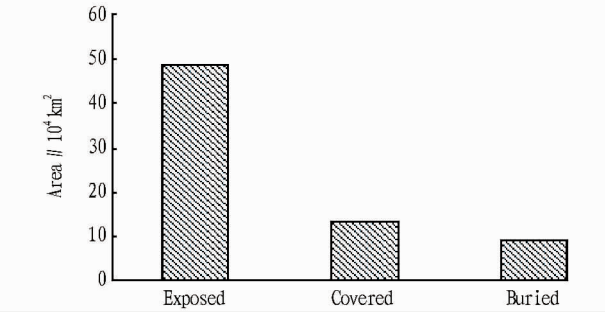

Fig. 1 Areas of various karst environments in southern China

Most parts of the bare karst landscapes have exposed bedrocks, only a small portion of this karst type associated with gentle slope or located in depressions has thin soils. The soil thickness is usually not more than 0.5 m, while soil thickness in some bedrock cracks can reach 1 – 2m. A large number of surface karst features such as sink holes, doline, peak forest, karst hills *etc*. can be seen on ground surface in bare karst environments; at the same time, underground karst features (cracks, dissolution pores, underground rivers and caves) can be seen everywhere in underground karstic networks and galkries. As the exists of ground and underground double – layer-space, soil and water resources are easy to escape through the underground pipelines, resulting in the surface drought; additionally, uneven precipitation and the poor drainage capacity of some underground rivers in rainy season can easily lead to depression floods; shortly after the heavy rainfall, a lot of surface water flows into the underground, which usually leads to the drought on ground. Insufficient water and soil, frequent drought and flood are main factors to restrict the land use in bare karst environments.

3.1 Directions for land use in natural vegetation areas in bare karst environments Due to human activities, natural forest in bare karst environment has been less likely to be seen. Currently, it is only some remote areas such as Maolan, Guizhou province, the top of Jinfo Mountain, Chongqing city, and Shennongjia, Hubei *etc*., where the primitive evergreen forest can be seen. The natural vegetation is the gene pool for tropical and subtropical karst ecosystems and the major base for biodiversity conservation in karst areas. If the primitive woodland is damaged, there will be no longer the gene source which is required for ecological restoration of the rocky land, and this will cause huge disasters to the karst ecosystem. Therefore, the directions for land use of original karst ecological areas shall be based mainly on conservation of native plants, animals and biodiversity, protecting and nurturing the endemic and rare species. Meanwhile, excessive tourism activities, which will result in land occupation and environment damage and pollution, shall be properly controlled. If necessary, the protected areas can be appropriately expanded, with the habitants in the core areas moved to the edge of the protected areas.

3.2 Problems and solutions for land use in rock desertification areas in bare karst environments Rock desertification regions in bare karst environments have large areas, including mild, medium and severe desertification areas. Recently, due to the rapid increase of population and the increasing intensity and extent of land use, the cultivated sloping lands in most parts of these areas have been extending to the top of the hills. Because of sparse vegetation, insufficient water resource and high proneness to droughts and floods in karst rock desertification areas, the soil and water conservation and ecological restoration shall be taken as the basic principles for land utilization; both ecological and economic benefits shall be emphasized for economic development and new rural construction; and ecological virtuous cycle shall be used as one of the appraisal indicators for land use and economic development. In order to implement above principles, followings should

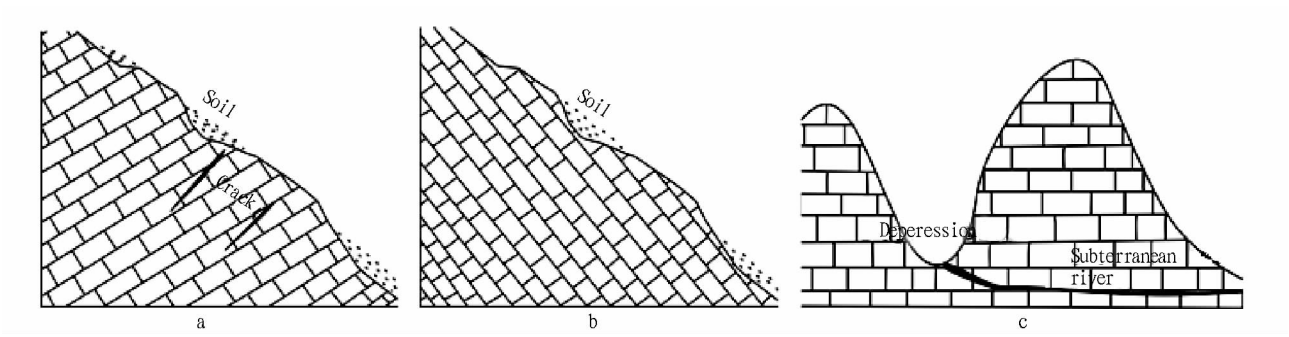

Fig. 2 Bare karst environments

be undertaken:

(1) To make efforts to construct water conservation forest and provide water source guarantee for reasonable land use in bare karst areas. In some peak cluster areas with lush vegetation or good ecological restoration, springs in epikarst zone always have large and continuous flow regardless of seasons; while other peak cluster-depressions associated with sparse vegetations often have dried springs and harsh environment[10]. Therefore, preventing excessive deforestation and protecting ecological environment are first tasks for land utilization. Generally speaking, the upper and middle parts of karst peaks and hills are suitable for water conservation forests. Water conservation forests can not only preserve water resources, but also prevent water and soil erosion; these forests are usually called by the villagers as "Fengshui Forest". If the bush wood is damaged in a short period, soils will be carried down to depressions by runoff quickly, which will result in obstructions of the depression sink holes, cracks or even underground rivers as shown in Fig. 2c, and subsequently form harsh environments that the floods occur when it rains and the droughts happen just after the rain.

(2) To control the population growth to reduce population pressures on land resources in the bare karst areas. As for the severe rock desertification areas, the ecological migrations can be taken into account; part of villages can be moved to the surrounding areas with good ecology; at the same time, the scattered settlements on the slopes can be gathered appropriately to reduce the population pressure on the degraded land.

(3) To lay down land use planning and strictly control the scale of sloping farmlands and construction lands. Land use policies have obvious influences on land use and land cover change in karst areas[11]. Therefore, feasible land – use planning for bare karst areas shall be formulated according to both national polices and local conditions. Comprehensive planning of mountains, rivers, farmlands, forests and roads should be set down for karst depressions and valleys; and the scale and spatial layout of shrub and grass lands, farming lands and construction lands must be reasonably determined. Specially, the sloping farmlands with steep slopes shall be timely converted to abandoned lands or shrub and grass lands; sloping lands and settlements ought to be placed at the lower part of the karst hills; some of the bottom of depressions which have periodical floods shall be free from establishment of settlements and land use projects; some countertrend karst slopes (Fig. 2a) with gentle slope and non-soluble interlayers will have slightly more soils, and are suitable for appropriate reclamation. According to current researches, soil erosion rate is generally not very high at the upper of the karst hills; the max erosion rate appears at the middle sections; in general, with the occurrence of lower erosion rates or even soil depositing, thicker soil layers, which are most beneficial to agricultural production, often exist in the lower parts of karst slopes[12]. The dip slopes as shown in Fig. 2b are easily evolved as the severe desertification areas after its vegetation is damaged. Such slopes shall be principally converted to abandoned lands and subsequently used for closing for forestation. Although it's hard to improve the soil coverage within a short time after conversion to abandoned lands, but the drought – enduring and rupestrine plants can grow in the cracks of bedrock, which will help the ecological restoration in rock desertification lands to some extent.

(4) To carry out land consolidation project and reduce water and soil loss by combining the engineering techniques and ecological measures. As the carbonate rock covered large areas, the farming lands which generally have small plots with thin soil layers, usually scattered between the exposed limestones; such lands are commonly known as "bowl-bowl soil" (Fig. 2). Therefore, conserving both water and soil, preventing aggravation of rock desertification are two tough tasks. Engineering measures are important for land consolidation and soil and water conservation in karst rock desertification areas. As intersection angle between the slope and strata can help to retain soils, the horizontal terrace and stone block ridge are applicable for countertrend slopes as shown in Fig. 2a, which have got better ecological and economic benefits in karst valleys in the east of Fuling district, Chongqing, *etc*[13]. By building runoff channels in karst hills at Nanping town, Nanchuan district, Chongqing city, the rainfall during the storms has been retained in the reservoir for the use in the dry season. This will have a better effect in reducing soil and water erosion and increasing irrigation and drinking water resource. In addition, flushing desilting basins can be built around the depression sink holes to store silt and sand taken from the upper part of the slopes, and retain water resource in the little reservoirs; silt and sand can be returned to slopes manually. A better effect will be achieved by combining engineering measures and biological techniques. In

some areas, in order to better hold up soil resources in the horizontal plots, biological fence technology has been successfully used and widely applied.

(5) To persist in emphasizing both ecological and economic benefits, and take into account planting economic forests, fruit trees and medicinal plants when land utilization and agricultural production is conducted. The plants which are suitable for karst environment such as *Lonicera japonica* and *Ilex kudingcha C. J. Tseng* can be used not only to restore the ecology, but also to increase the income of local habitants; such practices have been successfully applied in many karst areas. *Zanthoxylum bungeanum* has been planted in karst slopes on a large scale in Nanchuan district, Chongqing. According to the rupestrine, dry and alkaline features of the karst environment, native plants, which have high drought resistance, often get high survival rates; if there are some breakthroughs in seed propagation techniques, such plants will play important roles in ecological restoration in rock desertification areas.

(6) To notice the land use problems which are aroused from karst water resource development and utilization to prevent karst collapses. Surface water is stored in rivers, lakes and surface karst springs, while groundwater is mainly distributed in underground rivers and caves, *etc*. Firstly, to make great efforts to increase the runoff and outflow time of the surface karst springs and provide water resources required for land development and use on the spot. Secondly, to investigate the numbers, runoff and distribution of the subterranean rivers for water resource utilization. Water for land development can be pumped from sink holes and karst windows of underground rivers, but excessive pumping shall be prevented to avoid land destruction, such as karst collapse. Additionally, feasible measures must be taken to avoid droughts and floods in upstream areas, because some construction projects in the underground galleries can cause substantial water level fluctuation of underground rivers. At present, phenomenon that some sink holes are used for drain outlets in some karst areas should be prohibited and curbed.

4 Problems and solutions for land use in the covered karst areas

In the covered karst areas, the various loose or semi – consolidated sediments are deposited on the surface of soluble rocks (Fig. 3); in southern China, the most common overlying sediment is red soil. Geologically, such areas are usually faulted-basins or karst depressions formed due to geological processes, dissolution and erosion. As for horizontal spatial distribution, covered karst areas are transitional zones which the covered and bare karst environments are distributed alternatively or linked together. The covered karst environments exist generally in central basins, and bare karst types often exist in edge of the basins, in where elevation is generally higher than that of central basin. Huaihua basin, Hunan province, and Xiushan basin, Chongqing city, are typical types of the covered karst environment. Underground karst features, such as stone teeth, karst stone volume, *etc*. can often be seen in constructions in Huaihua basin (Fig. 3). Guilin basin is a covered karst environment too, in where many isolated peaks stand on the peak – forest plain.

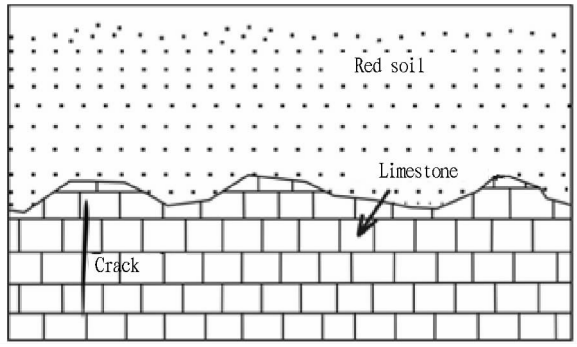

Fig. 3 Covered karst environment (Huaihua basin, Hunan province)

In general, compared with bare karst environments, covered karst environments usually have better conditions for land use due to continuous soil coverage. Therefore, most parts of such areas have been converted to gathering areas of agricultural production and cities. However, along with the accelerated urbanization, some environmental problems may be produced under the inappropriate land use, such as sharp decrease of agricultural lands, forest degradation, water and soil loss in low hills and valley slopes, groundwater pollution, landfill and blocking channels of karst spring during urbanization construction, karst collapse, *etc*.

Long-term planning for land use shall be proposed and carried out, for reasonably determining the proportions of various lands, and comprehensively configuring spatial layout of different land use types (construction land, agricultural land, industrial land, forestry land and economic forest land). As some hills and valley slopes in the basins have steep slope, major land use types should be forest and green lands, which have better anti – erodibility. For some low hills associated with gentle slope and good soil coverage, fruits trees such as *Citrus*, *Myrica rubra*, *etc*., economic forests such as *Camellia oleifera*, *Phyllostachys edulis*, *etc*. can be planted; however, water and soil loss shall be prevented to avoid the appearance of secondary karst rock desertification in the basin. The paddy or dry farming can be conducted in the gentle slope districts, and the crop species can be selected based on different local conditions. Presently, most parts of Huaihua basin have been developed as urban areas; while in suburban regions, there are still many paddy fields, *Camellia oleifera* forests and orchards, such combination is appropriate and beneficial. As karst basins in Guizhou plateau always have poor water resource condition, besides rice, the dryland crops including corn, sweet potato also can be taken into account. Karst basins and valleys are usually discharge areas of karst water, so there are often some karst springs in the karst basins. There are several karst springs around Luyang and Huaqiao town, Huaihua city, Hunan province, their stable flow range from 1 to 10 liters per seconds. If karst springs can be effectively protected during urban constructions, it will not

only bring convenience to the residents, but also greatly enhance the image of the city (such as Jinan). However, in some places, karst springs will be buried or directly blocked in the drainage during the urban development processes. In order to exploit tourism production, the topsoil in some places is deliberately removed, resulting in appearance of some naked stone teeth, karst stone volumes, *etc*.; such practice is likely to damage the water supply areas of karst springs, reduce or even cut off the water flow. As the loose sediments have certain water permeability, the garbage sites and drain outlets in the basin shall be carefully set up. Karst collapse is the major land use problem in covered karst environments; this phenomenon, which is mainly attributed to the over-pumping of ground water, is easy to happen in covered karst environments with thin soils. In addition, ground collapse and groundwater turbidity arising from coal mining are also outstanding in the covered karst areas. In order to prevent ground collapses from happening, the thickness of the overlying soils and the hydrogeological conditions shall be firstly ascertained, followed by setting down groundwater and mineral exploitation and utilization planning to prevent overexploitation; land reclamation planning shall be presented and carried out in collapse and waste mining areas.

5 Current situations of land use in buried karst areas and problems required to be noted

The buried karst environment (Fig. 4) is a type of environment, where the top of the carbonate rocks is covered with non-soluble rocks (sandstone or shale), or this areas have some interbeds of carbonate rocks and non-soluble rocks. Sichuan basin is a representative of this type; additionally, the interbed of limestone and non-soluble rocks also can be seen in the Paralleled ridge-valley of east Sichuan. As the surface of these areas is covered with soil and non-soluble rocks, the ground landscapes are basically consistent with those of non-karst areas. As compared with bare and covered karst environments, buried karst environments have the best land use conditions. However, due to dense population and developed industrial and agricultural production, the land and pollution problems arising from tourism development, oil and gas exploration, deep karst water development and tunnel construction, *etc*., shall be noted.

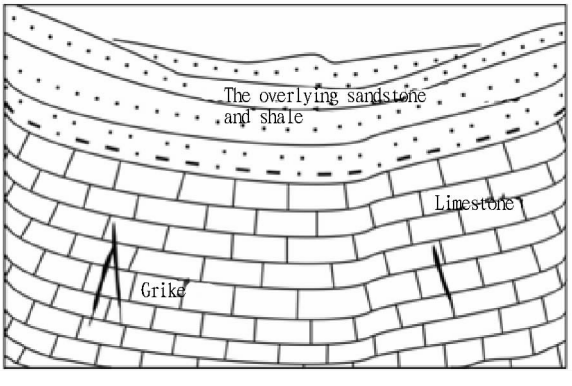

Fig. 4 Type of buried karst environment

Generally speaking, there are few factors to restrict the agricultural production, while there are still several problems such as sparse vegetation and soil erosion during land use in purple soil-covered areas in Sichuan basin. Due to interbed of the limestone and the non-soluble rocks, there are many karst springs and hot springs in the Paralleled ridge-valley of east Sichuan, among which the north hot-spring in Chongqing may flow through the underlying carbonate rock layers, although it flows out from sandstone and shale cracks of triassic Xujiahe formation. Some of the hot springs in Kangding County, Sichuan, also flows through the interbeds of soluble rocks and non-soluble rocks. Because of the water supply areas of deep karst water are usually located at the naked soluble rocks or non-soluble rocks in the hills around the karst basins or depressions, excessive tourism development activities, limestone quarry, *etc*., will not only occupy land resource, but also damage the vegetation, which will finally reduce the karst water supply. In the case of thin overlaying sand shale, land development and construction *etc*., can damage the overlaying strata, which may result in the overlaying collapse and destroy the cycle process of deep karst water. In these regions, the karst water, which is buried deeply, always has slowly cycling process; after being polluted, the purification process is also slow. In order to prevent the reduction of karst spring's supply and occurrence of karst water pollution, it's important to protect the vegetations of water supply areas in the surrounding mountains, in where ground surface is often covered with carbonate rock or sand shale. Recently, there are many highway and railway constructions in the buried karst areas, their tunnels often pass through several strata; there has been reported that construction of roads and tunnels in buried karst areas may lead to decrease or exhaustion of the karst spring flow[14]. In buried karst environments, along with the increasing exploration and mining activities against the resources like geothermal water, oil and gas, pollution is increasing. For the sake of achieving sustainable development, on the one hand, the infiltration of the pollutants into the underground karst space and the aquifer via drilling holes shall be prevented; on the other hand, land pollution in mining areas arising from the mining processes should be noted and governed.

6 Conclusions

Bare karst environments, in where soil is thin, water is scarce, karst rock desertification is often severe, and land use problem is outstanding, are widely distributed in south China. As for the bare karst environments, water conservation forests construction, population control, land consolidation and rock desertification control, *etc*., are all important measures for land use and environmental conservation; persisting in both ecological benefits and economic benefits, properly configuring limited land resources are the most important principles for new countryside construction. In the covered karst environments, there are soils and other loose sediments deposited above the surface of the soluble rocks, agricultural conditions

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provinces were evaluated to study the characteristics of temporal rule and spatial distribution.

(1) Compared with popular data, the emission of agricultural pollution through list analysis were reasonable. Results suggest that agriculture pollution has become another large pollution source and hasn't been controlled.

(2) DEA method has been applied to evaluate the potential and efficiency of carbon emission, as well as environment efficiency under the weak process condition. Results show that the reduction of COD, TN and TP in agriculture reached an annual rate of 5.08 million ton, 1.15 million ton and 0.12 million ton respectively.

(3) Based on the features of Chinese agriculture, this paper studies factors influencing the improvement of carbon emission. Results show that education per capita, family income and the salary had positive effect on carbon emission, while other factors, fixed capital, sowing area and labor force coefficient as well as family population would either restrict the improvement of carbon emission, or show certain uncertainty.

The policy significance of this study is as follows:

Firstly, agricultural pollution is another large source of pollution after industrial pollution. As economy booms, agricultural pollution becomes increasingly outstanding, which because the agricultural pollution directly affect food safety as well the living condition. Thus, it is imperative to reduce production. Besides, the potential to reduce carbon emission in Central West China was larger than that in East China, which suggested that the pressure to reduce carbon emission concentrates on the place where agriculture is the primary industry. Agriculture scale and intensive degree are factors which restrict the improvement of efficiency in carbon emission. At last, the agricultural pollution control can not be separated from farmers' participation and enthusiasm. Besides from improving farmers' education level, government will take measures to reduce carbon emission, which can effectively improve the use of fertilizer and agriculture medicine.

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are better than that of bare karst types, so these karst types are usually gathering areas of agriculture and cities; but it is still necessary and meaningful to prevent the occurrence of unreasonable land use, and control or cure problems such as the karst spring exhaustion, secondary karst-rock-desertification and karst collapses *etc*.. In buried karst environments, there are soils and overlying non-soluble rocks above the surface of the carbonate rocks, so these karst types are the best areas for agricultural production. Unreasonable land use which can cause overlaying strata collapse, soil erosion, and supply area pollution of karst springs should be prevented. Exploiting gas and coal may result in deep karst water pollution and land contamination in the mining areas, these phenomena also shall be curbed.

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