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Spatial Delineation of Gold Resource Planning Regions Based on Multi-Objectives

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Abstract

Current gold resource management in China has faced dual challenge from guaranteeing metal supply (quantity) and resource upgrade and transformation (quality). Although China has proposed the setup of seven gold resource planning regions to resolve this challenge, how to spatially-delineate these regions has not been specified. In this study, we identify three criteria for the spatial delineation of these 7 planning regions, i.e., (i) geographic distance from any mining right to the center of its planning region is shorter than to the center of any adjacent planning region; (ii) the size of each planning region should be similar; (iii) the amount of gold production capacity in each planning region should reach a certain proportion threshold of the national total (namely the "goal value"). Referenced from the existing spatial delineation methods, Voronoi diagram and buffer analysis are used to calculate the spatial scope necessary to satisfy these three objectives, from both resource development (mining right-level) and management (administrative county-level) perspective. The results show that with the goal value rising from 40 to 60%, the planning region size, the number of mining right and the administrative county involved in the planning regions all increase substantially, but the growth rates are different. Our work integrates the mineral resource management and geographic analysis, and such methodology is also applicable on other commodities.

Keywords: China; gold resource planning regions; spatial delineation; Voronoi diagram; buffer analysis

INTRODUCTION

Gold is a key strategic metal, and is indispensable for national economic and social development (Pian and Santosh, 2019). In China, since the Open-Door policy in 1978, gold mining has provided crucial support to the rapid economic growth and infrastructure buildup (Meng et al., 2018). However, under the current transformation of the Chinese economic development mode, ecological/environmental protection has faced unprecedented challenges (Wang and Chen, 2019). With gradual implementation of various ecological/environmental protection polices and conservation areas setup, the Chinese gold mineral industry has to transform from the previous small-scale, scattered and less- organized mining (Zhu, 2016) into more-integrated green exploitation (Shen et al., 2016). Stable gold supply is indispensable for China's economic and social development (Shen et al., 2018). In the year 2018, gold consumption in China was 1151.4t, accounting for 26.5% of the global total, and ranking the world's first in six consecutive years (Guo et al., 2019). Moreover, China has increased its external gold dependency to over 50% in 2018 (Wang et al., 2019). The primary means to safeguard the gold resources supply is to ensure self-sufficiency and effectively utilization on the domestic resources (Daw, 2017). Taken together, China is facing dual pressure from guaranteeing gold resource supply and production upgrade and transformation. To resolve these problems in an integrated way, the National Mineral Resources Plan (2016-2020) was proposed in 2016 by the People's Republic of China (PRC) State Council (PRC State Council, 2016), which put forward a goal to establish 7 gold resource planning regions. These planning regions comprise key mineral zones and belts with favorable metallogenic conditions, sizable resources and good prospecting potential (Wu and Zhang, 2019).

Delineation of key regions and spatial regulation development are effective means for natural resources management, ecological/environmental protection, spatial resource development/conservation planning, and urban development optimization. For example, in terms of environmental protection, delineation of natural protection zones and formulation of strict management policies is one of major initiatives for many countries in ecological/environmental protection (Shafer, 1999; Shelford, 1941; UNESCO, 1974). In terms of biodiversity protection, identification of important areas is the primary step to formulate and implement protection plans (Knight et al., 2008). To maximize the protection effect with limited investment (Myers et al., 2000; Roberts, 2002), many countries have delineated prime protection areas of biodiversity protection (Blasi et al., 2011; Schouten et al., 2010). In terms of spatial planning, countries such as Germany, U.K. and Japan have paid more attention to problem-based policy area delineation (European Commission, 1999; Koyama, 2011). For example, to facilitate balanced development, Germany divided its major cities into three groups that need special development, optimized development and special ease (Blotevogel, 2006). In terms of mineral resource management, well-endowed countries such as the UK, US, Russia, Canada, and Australia tend to pay more attention to the spatial governance of mineral resources development, which evokes the idea of partition management (Wagner et al.,2006; Scott and Dimitrakopoulos, 2001; Makarov, 2009). From the published studies, it is found that regardless of the resources, environment or urban development, partition management policy tends to require a definite spatial scale, thus, spatial boundary delineation is critical for resource management. Policy implementation involves the process of spatial resource allocation (He et al., 2019).

Gold resource planning regions are key regions of Chinese gold distribution, and are important policy tools for partition management; their essence is the carrier of mineral resource management system. Amiri et al. (2019) demonstrated that system quality enhancement can facilitate more-effective natural resources utilization, strengthen the progress of the manufacturing industry, thus, facilitate higher economic growth. However, to the best of our knowledge, since the concept is relatively new, the 7 gold resource planning regions have only names, their spatial scope is not well defined, which create problems for effective resource management. There is only a small amount of research on this topic, and the delineation work is largely qualitative (Ma, 2015; Luo et al., 2016; Wang and Niu, 2016). The significance of this study is to use a quantitative method to calculate the spatial scope of gold resource planning regions in China based on multiple objectives, and propose the boundaries both for establishing and managing these gold resource planning regions. The former refers to the mining districts that the planning regions contain, and the latter refers to the county-level administrative regions that the planning regions involved. Making the gold resource planning regions become the real space policy area, so that the government can formulate special policies for specific mining rights in the planning regions to bring their roles into full play.

The chapter structures are arranged as follows: part II is the literature review of mineral spatial policy areas in and outside China, and the current methods for delineation of spatial policy areas; part III is the design of methods to delineate iron ore resource planning regions; part IV is the analysis results and discussion; part V is the conclusion and suggestions on policy making.

Literature Review

The spatial area for mineral resource management is very popular internationally, most of the countries define policy areas to protect important domestic mineral resources from disturbing by other construction activities. In the UK, Mineral Safeguarding Areas is delineated to maintain an adequate and steady supply of energy, construction and industrial minerals that can be indigenously produced (Wrighton et al, 2014; Weber et al., 2008; McEvoy et al., 2007). In addition to the safeguarding areas, some local mineral resource plan in the UK also requires the delineation of areas for future working, including Specific Sites, Preferred Areas and Areas of Search (Shropshire County Council and Telford & Wrekin Council, 2000). The United States also pays great attention to the protection of mineral resources for utilization. In Carroll County, Maryland, Mineral Resource Overlay (MRO) zones are imposed on other zoning districts where mining is seen as a compatible activity and there are known economic mineral resources present (Dunn et al., 1980; Carroll et al. 1999). In Queensland and Western Australia, significant resource areas identified as Key Resource Areas (KRAs) and Priority Resource Locations (PRLs) respectively, which are protect from development that is incompatible with extraction (Baker and Hendy, 2005). In order to guarantee the stable development of domestic metal industry, the former Soviet Union built a number of mineral supply areas (E.И., 1985).

The partition management of China’s mineral resource date back to the beginning of 21st century, the main purpose of which is to gradually optimize the small-scale and scattered exploration pattern (Zhu and Mo, 2017). In the year 2001, the PRC government issued the National Mineral Resources Plan (2001-2010), began to introduce spatial policy areas to regulate mineral resources exploration. Exploration/mining areas were classified into three groups, i.e., those where exploration of mineral resources are (1) encouraged, (2) restrained and (3) prohibited (for ecological/environmental conservation). In 2005, for interestedly resolving a number of prominent problems in coal industry, and guaranteeing national economic development, the PRC State Council proposed a goal to construct 13 large-scale coal planning regions (General Office of the PRC State Council, 2005). Based on this experience, the Chinese government explored to construct planning regions among other major mineral resources. In January 2009, the National Mineral Resources Plan (2008-2015) was issued (Ministry of Natural Resources of PRC, 2009), with a goal to establish 75 mining economic areas. However, because of the unclear boundary and lack of following promoting policies (Nie et al., 2015), its due role has not adequately played out. Energy and resource planning regions are upgraded version of the mining economic areas. The 7 gold resource planning regions defined are part of China's 103 energy and resource planning regions that proposed in 2016, and the establishment aims to: (1) guarantee the baseline of national gold resource supply; (2) promote sizable and intensive gold resource development, and completely resolve the problem of small-scale disorderly mining; (3) implement China's regional coordinated development strategy and promote the coordinated development of regional mining economy.

In China, previous research was focused on the delineation of mining economic areas. Wang et al. (2011) proposed the three-level mining economic delineation scheme based on the 75 mining economic areas; Song et al. (2014) suggests using ArcGIS technology and multivariate statistical analysis to complete the delineation work. Some other scholars also put forward some basis and principles of delimiting mining economic areas (Cao and Li, 2015). Since the concept of energy and resource planning regions was put forward, researchers began to pay more attention to its delineation issue. Ma (2015) has defined 11 iron ore resource planning regions nationwide by using SOFM cluster analysis method; Luo et al. (2016) proposed 27 energy and resource planning regions in Sichuan Province based on the analysis of some mineral information maps. Wang and Niu (2016) demarcated 42 non-ferrous metal resource planning regions by establishing an evaluation index and using map superposition method.

It can be seen that spatial area for mineral resource management in the UK, the United States and Australia are mainly focused on the protestation of domestic minerals from sterilization by other forms of development. While in China, their tasks are more diverse, this requires that the delineation work must satisfy more needs. The previous research has taken various mineral resource information into account when delimiting planning regions, but their methods are mainly qualitative, and unable to meet multi-objective requirements.

The spatial-policy-area delineation methods in the current studies can roughly be divided into four categories namely: (1) the experience of relevant experts, which is largely affected by the expert's knowledge and individual experience (Cowling et al., 2003; Wang et al., 2011); (2) by creating a set of predefined standards (Cao and Li, 2015; Brown et al., 1995; Eken et al., 2004; Myers et al., 2000), e.g. to make some strict delimitation principle, or some standards based on the distribution of the natural resource itself. For instance, in the UK, the boundary of Mineral Safeguarding Areas is determined by applying a specified buffer to the mineral resource outline, for the sand and gravel, the buffer is set to 250m; (3) to identify areas that attain near-optimal solutions for delineation targets, e.g., spatial optimization model (Toregas et al., 1971; Church and Revelle, 1974; Zvi et al., 2019; Okabe and Suzuki,1997; Watts et al., 2009). For instance, Watts et al. (2009) identify biodiversity conservation zones that could minimize the total cost while achieve a variety of conservation and land-use objectives; (4) adopting methods such as spatial overlying or clustering analysis (Xiang et al., 2015; Zhang, 2014), as used in the delimitation of ecological redlines by Yang et al. (2018). Among these four categories of methods, the method (3) is quantitative and can satisfy multiple objectives, which are the most suitable for the delineation of gold resource planning regions. Therefore, this study proposes to use method (3), and design a spatial delineation method that can achieve the three aims of gold resource planning regions above-mentioned.

METHODOLOGY

Study Methods

Spatial delineation of the gold resource planning regions in this study is in line with the following rules:

(i) For a certain planning region, the geographic distance from all its mining rights to its center is shorter than to the center of the adjacent planning region. This rule ensures the spatial concentration of gold mining rights in the planning regions. Minimizing the areal scale can improve the focus of resource planning regions for effective management, and thereby boost the scale and intensity of mineral resources exploitation, in accordance with the industrial cluster theory (Helsley, 2004).

(ii) The size of each planning region should be similar. This corresponds to the "coordinated development of regional economy" strategy, which is one of the current national priorities in China (Xi, 2017). Similar size of the gold resource planning regions can avoid large differences in regional economic development.

(iii) The production capacity in the gold resource planning regions have to be above a certain proportion of the total gold production capacity in the country, which set a baseline for guaranteeing domestic resource supply.

The spatial delineation of gold resource planning regions can be regarded as a multi-objective spatial optimization problem, which needs to be calculated by several methods. In the published spatial optimization methods, The Voronoi diagram (Zvi et al., 2019; Okabe and Suzuki., 1997) is able to comply with Rule No. (i); GIS buffer analysis (Zhou et al., 2017) can better comply with Rules No. (ii) and (iii). Both methods have been extensively applied to the fields of urban planning, ecological protection, flood and disaster prevention/mitigation (Li et al., 2016). This study attempts to introduce both methods into delineation of the gold resource planning regions.

The Voronoi diagram is also called the Thiessen polygon, aims to divide a study area into polygons that are defined by Rule No. (i) (Voronoi,1909; Okabe et al., 2009). The Voronoi diagram is generated with ArcGIS software to identify the largest threshold of each gold resource planning region, and the planning region boundary cannot exceed its Thiessen polygon scale.

Based on the Voronoi diagram generated, buffer analysis is performed to constrain the scope of gold resource planning regions. Buffer analysis is a polygon layer on the basis of point, linear and planar entity, and automatically creates a buffer area of a certain width around it, thus can identify and analyze the possible association rules between spatial objects and surrounding things, environment, as well as the scope and degree of their influence (Wu et al., 2001; Bonham-Carter, 1994). In terms of the procedures:

(1) set a minimum percentage of production capacity in the gold

resource planning regions to the total capacity of China (hereinafter referred to as goal value);

(2) create a buffer zone around the planning region center, and calculate the minimum buffer radius to achieve the goal value.

To implement Rule No. (ii), this study set the radius of each planning region buffer into a single constant value. For the steps of analysis:

(1) calculate the Euclidean distance between the center of each gold resource planning region and the gold mining districts in its Thiessen polygon;

(2) take the planning region center as the center of a circle, and take a certain distance as the radius to create a buffer zone, and calculate the production capacity of the mining districts in the buffer zone;

(3) take 10 km as step length to enlarge the radius of the buffer zone, repeat steps (2) and (3) until the radius reaches its maximum distance. In this study, the minimum radius is 0, while the maximum radius is the Euclidean distance between each gold resource planning region and its furthest gold mining right;

(4) take the radius as x-axis and goal value as y-axis to generate a 2D map, which yield the radii of gold resource planning regions under different goal values. Filter the mining rights in each gold resource planning region within such radius, and draw the minimum outsourcing polygon. This gives the spatial scope of gold resource planning regions under their corresponding goal values.

Data Sources

The location and production capacities of gold mining rights in China are the main two indices in this study. The base map uses the PRC administrative map 2006, and the districts under the jurisdiction of the same prefecture level city are merged into one polygon. This results in 2366 county-level administrative regions. Location of the gold mining rights in China and their production capacities data were collected from PRC National Mineral Exploration and Mining Information Publicity System (http://kyqgs.mnr.gov.cn/), and the data cover the whole mainland China.

RESULTS AND DISCUSSION

Spatial Delineation of Gold Resource Planning Regions

The 7 gold resource planning regions are namely Zhaoyuan-Laizhou (Shandong), Xiaoqinling-Xiongershan (Henan), Zijinshan (Fujian), Zhenfeng-Pu’an (Guizhou), Eastern Kunlun (Qinghai), Southern Gansu, Pingjiang-Liling (Hunan) (Fig. 1). TheVoronoi diagram was constructed based on the center point of the planning regions, and the result are shown in Figure 1.

Figure 1. Voronoi diagram of the 7 gold resource planning regions in China.

The x-axis was taken as the radius of gold resource planning regions and y-axis as the goal value (Figure. 2). As shown in Figure. 2, with increasing radius of the buffer zone, the goal value increases rapidly first, reaching 60% when the radius reaches ~400 km. When the radius reaches >900 km, the growth of goal value becomes very slow. Considering that gold is a major mineral in short supply in China, with a middle degree of external dependence, and the spatial distribution of gold mining rights is relatively scattered, this study sets the goal value between 40% and 60%, to explore the boundary scales of gold resource planning regions under 60%, 50% and 40% goal values. It is calculated that, when goal value = 60%, the buffer zone radius of the 7 gold resource planning regions is required to reach 400 km; when goal value = 50%, the buffer zone radius is required to reach 190 km; when goal value = 40%, the buffer zone radius is required to reach 70km.

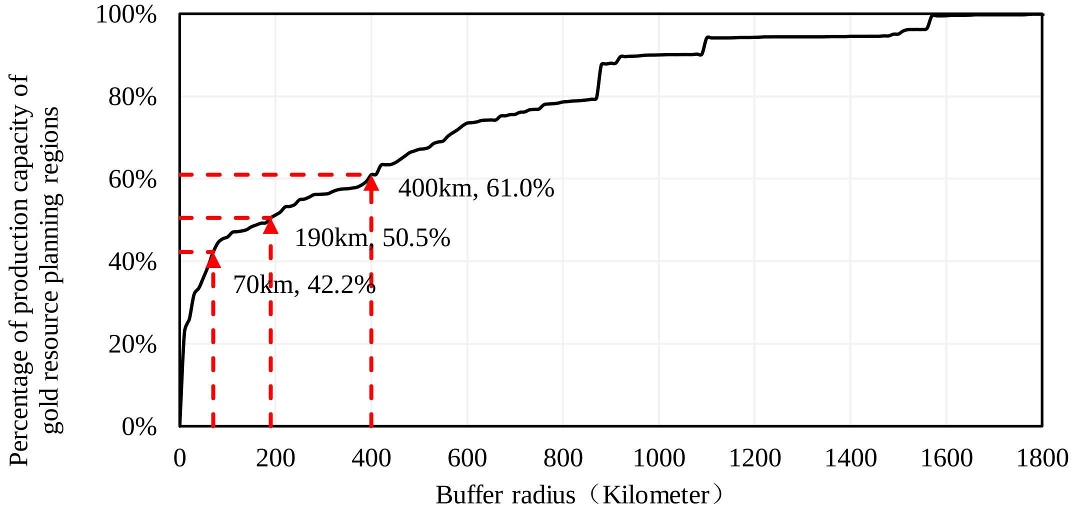

Figure 2. Graph of goal value variation with different buffer zone radius.

After we select the gold districts in the buffer zone, and calculate the minimum outsourcing polygon of the mining districts, we can get the boundary scales of the gold resource planning regions under 60%, 50% and 40% goal values, as shown in Figure 3. It should be noted that Zijinshan planning region has only two mining rights and one single mining right with goal value of 50% and 40% respectively, which cannot automatically generate the smallest outsourcing polygon, hence, the spatial scopes in these two cases were not shown in the Figure.

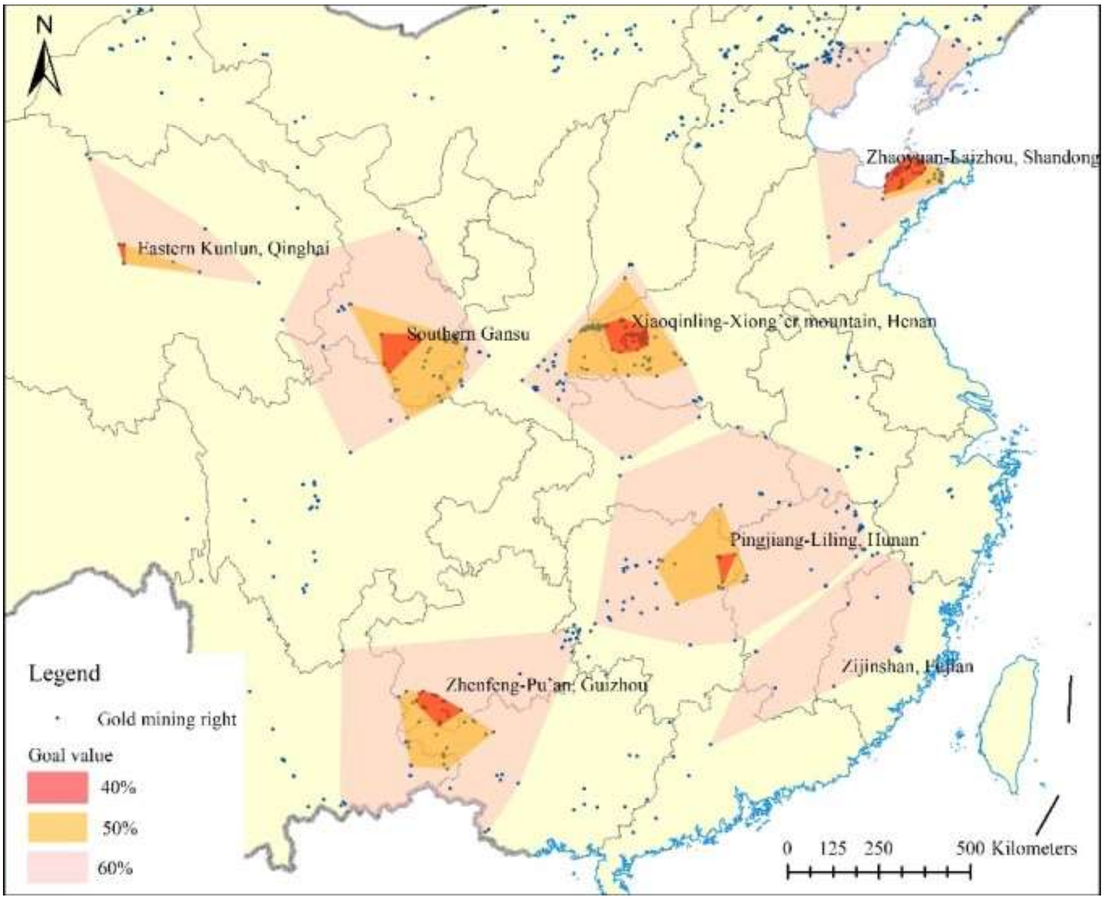

Figure 3. Scales of gold resource planning regions with goal values of 60%, 50% and 40%

Assessment and Analysis to Delineation Results

Basic Index Statistics

<u>(1) Planning regions delineation with goal value of 60%</u>

There are a total of 582 gold mining rights in the 7 gold resource planning regions, accounting for 53.2% of the country. Among the 7 planning regions, Zhaoyuan-Laizhou and Xiaoqinling-Xiongershan have more than 100 mining rights, followed by Pingjiang-Liling, (> 80), Southern Gansu and Zhenfeng-Pu’an (each >60). The Eastern Kunlun has the least number of gold mining rights (10).

The total gold ore production capacities in the 7 planning regions are 101.33 Mt, accounting for 61.0% of China (Table 1). Among the 7 planning regions, Zijinshan has the highest gold ore production capacities (38.2 Mt, 23.0% of national total), followed by Zhaoyuan-Laizhou (23.23 Mt, 14.0% of national total). Xiaoqinling-Xiongershan and Southern Gansu also have more than 10 Mt capacities. The Eastern Kunlun has the least gold ore production capacities (1.31 Mt, 0.8% of national total).

In terms of areal size, the 7 planning regions cover a total area of 1,189,941 km^2, 12.4% of national total. Among the 7 planning regions, Pingjiang-Liling is the largest (~313,830 km^2), followed by Zhenfeng-Pu’an (~246,141 km^2) and Southern Gansu (~210,746 km^2), and the remaining four planning regions are under 200,000 km^2. The Eastern Kunlun is the smallest (~61,499 km^2).

Table 1. Statistics of 7 Gold Resource Planning Regions with A Goal Value of 60%.

Name	No. of Mining Rights	Production Capacity of Ore (10000 t)	Percentage (%) of National Total	Size (10,000 km^2)
Zijinshan, Fujian	18	3820	23.0%	119384
Zhaoyuan-Laizhou, Shandong	165	2323	14.0%	99854
Xiaoqinling-Xiongershan, Henan	178	1181	7.1%	138487
Southern Gansu	60	1134	6.8%	210746
Zhenfeng-Pu'an, Guizhou	62	844	5.1%	246141
Pingjiang-Liling, Hunan	89	699	4.2%	313830
Eastern Kunlun, Qinghai	10	131	0.8%	61499
Total	582	10133	61.0%	1189941

(2) Planning regions delineation with goal value of 50%

There are a total of 384 gold mining rights in the 7 gold resource planning regions, accounting for 35.1% of the country. Among the 7 planning regions, Xiaoqinling-Xiongershan has the most (149), followed by Zhaoyuan-Laizhou (115). Southern Gansu and Zhenfeng-Pu'an have more than 40 mining rights, and the remaining three planning regions are under 30. Zijinshan has the least number of gold mining rights (2).

The total gold ore production capacities in the 7 planning regions are 83.92 Mt, accounting for 50.5% of China (Table 2). Among the 7 planning regions, Zijinshan has the highest gold ore production capacities (37.53 Mt, 22.6% of national total), followed by Zhaoyuan-Laizhou (19.4 Mt, 11.7% of national total). Xiaoqinling-Xiongershan, Southern Gansu and Zhenfeng-Pu'an have more than 5 Mt capacities. The Eastern Kunlun only has less than 1 Mt gold ore production capacities.

In terms of areal size, the 7 planning regions cover a total area of 190,945 km^2, 2.0% of national total. Among the 7 planning regions, Xiaoqinling-Xiongershan and Southern Gansu are the largest (~50,916 km^2), followed by Pingjiang-Liling (~37,367 km^2) and Zhenfeng-Pu'an (~35,066 km^2). As there are only two mining rights in Zijinshan, it is unable to define the minimum outsourcing polygon, the actual area of these two mining rights is used instead.

Table 2. Statistics of 7 Gold Resource Planning Regions with A Goal Value of 50%

Name	No. of Mining Rights	Production Capacity of Ore (10000 t)	Percentage (%) of National Total	Size (km^2)
Zijinshan, Fujian	2	3753	22.6%	5.3
Zhaoyuan-Laizhou, Shandong	115	1940	11.7%	11091
Xiaoqinling-Xiongershan, Henan	149	974	5.9%	50916
Southern Gansu	46	762	4.6%	50671
Zhenfeng-Pu'an, Guizhou	41	689	4.1%	35066
Pingjiang-Liling, Hunan	25	245	1.5%	37367
Eastern Kunlun, Qinghai	6	29	0.2%	5829
Total	384	8392	50.5%	190945

(3) Planning regions delineation with goal value of 40%

There are a total of 210 gold mining rights in the 7 gold resource planning regions, accounting for 19.2% of the country. Among the 7 planning regions, Zhaoyuan-Laizhou has the most (92), followed by Xiaoqinling-Xiongershan (71). The remaining planning regions are all under 30. Zijinshan has only one gold mining right.

The total gold ore production capacities in the 7 planning regions are 70.17 Mt, accounting for 42.2% of China (Table 3). Among the 7 planning regions, Zijinshan has the highest gold ore production capacities (37.5 Mt, 22.6% of national total), followed by Zhaoyuan-Laizhou (17.53 Mt, 10.6% of national total). Besides, Xiaoqinling-Xiongershan has more than 5 Mt capacities. The Eastern Kunlun has the lest gold ore production capacities.

In terms of areal size, the 7 planning regions cover a total area of 27956 km^2, 0.3% of national total. Among the 7 planning regions, Xiaoqinling-Xiongershan are the largest (~7,946 km^2), followed by Southern Gansu (~6,630 km^2) and Zhenfeng-Pu'an (~5,534 km^2). There is only one gold mining right in Zijinshan, the area of which is 5 km^2.

Table 3. Statistics of 7 Gold Resource Planning Regions with A Goal Value of 40%

Name	**No. of Mining Rights**	**Production Capacity of Ore (10000 t)**	**Percentage (%) of National Total**	**Size (km^2)**
Zijinshan, Fujian	1	3750	22.6%	5.1
Zhaoyuan-Laizhou, Shandong	92	1753	10.6%	5816
Xiaoqinling-Xiongershan, Henan	71	549	3.3%	7946
Southern Gansu	11	434	2.6%	6630
Zhenfeng-Pu'an, Guizhou	21	375	2.3%	5534
Pingjiang-Liling, Hunan	10	132	0.8%	1692
Eastern Kunlun, Qinghai	4	24	0.1%	333
Total	210	7017	42.2%	27956

County-level Administrative Regions Involved in The Planning Regions

The county governments are the main policy-implementation and supervision bodies of gold resource planning regions, and the county-level administrative regions are the subject scope of gold resource planning regions. Therefore, it is necessary to make statistics on the county-level administrative regions involved in the planning regions, to find out who should take shoulders on the implementation of gold resource planning regions.

(1) Planning regions delineation with goal value of 60%

A total of 168 county-level administrative regions are involved in the 7 planning regions with goal value of 60% (Table 4, Figure 4), among which the Pingjiang-Liling has the most (38), followed by Xiaoqinling-Xiongershan (35). Besides, the Zhaoyuan-Laizhou, Zhenfeng-Pu'an and Southern Gansu has also >20 county-level regions. The Zijinshan and Eastern Kunlun both have below 20 county-level regions.

<u>(2) Planning regions delineation with goal value of 50%</u>

A total of 78 county-level administrative regions are involved in the 7 planning regions (Table 4, Figure 4), among which the Xiaoqinling-Xiongershan has the most (23), followed by Southern Gansu (17) and Zhenfeng-Pu'an (15). Zhaoyuan-Laizhou and Pingjiang-Liling both have 10 county-level regions. The Eastern Kunlun only has 1 county-level region.

<u>(3) Planning regions delineation with goal value of 40%</u>

A total of 30 county-level administrative regions are involved in the 7 planning regions (Table 4, Figure 4), which is 48 fewer than that of 50% goal value. Among the 7 planning regions, Zhaoyuan-Laizhou, Xiaoqinling-Xiongershan, Zhenfeng-Pu'an have more than 5 county-level regions, Zijinshan and Eastern Kunlun only have 1 county-level region.

Table 4. Numbers of County Level Administrative Regions Involved in The Gold Resource Planning Regions

Name	No. of Counties with Goal Value of 60%	No. of Counties with Goal Value of 50%	No. of Counties with Goal Value of 40%
Zijinshan, Fujian	11	2	1
Zhaoyuan-Laizhou, Shandong	28	10	8
Xiaoqinling-Xiongershan, Henan	35	23	7
Southern Gansu	25	17	5
Zhenfeng-Pu'an, Guizhou	27	15	6
Pingjiang-Liling, Hunan	38	10	2
Eastern Kunlun, Qinghai	4	1	1
Total	168	78	30

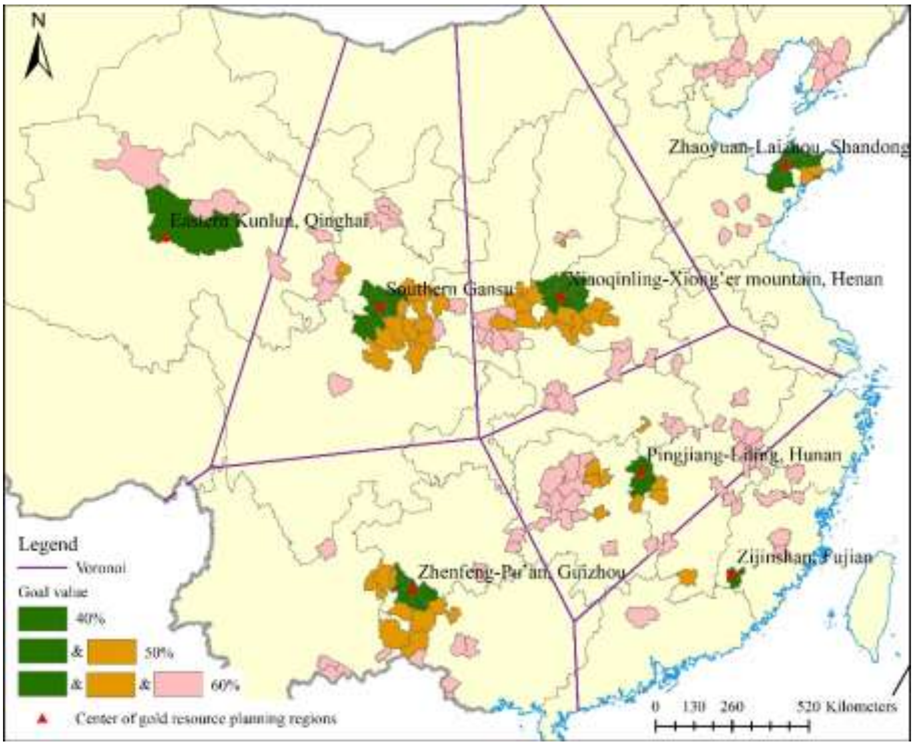

Figure 4. County-level administrative regions involved in the planning regions with goal values of 60%, 50% and 40%.

Comparison of Different Goal Values

Table 5 compares the changes of mining rights number, the size of the 7 gold resource planning regions and the county-level regions number under the three goal values. It is easy to see that with the increase of the goal value, the three indices all increase greatly, among which the planning regions' size has the largest increase, followed by the increase of the county-level regions number, and the smallest increase of mining rights number. When the goal value is increased from 40% to 50%, the size of the 7 planning regions increases by 772%, the number of county-level regions increases by 260%, and the number of mining rights increases by 83%. When the goal value is increased from 50% to 60%, the increased quantity of these three indices all increased, while the increased extend of these indices all decreased. Especially for the planning region size, the increased quantity is 94,6247 when the goal value changes from 50% to 60%, four times more than that of the goal value changes from 40% to 50%, but the increased extend is only about 1/2 of the former. The increase of mining rights number has minimum difference under these two cases.

Table 5. Comparison of Indices of Gold Resource Planning Regions with 60%, 50% and 40% Goal Values

Index	Mining Rights Number		Planning region Size		County-Level Regions Number	
	a	b	a	b	a	b
Increase (number)	174	198	21,5736 km^2	94,6247 km^2	48	90
Increase (%)	83%	52%	772%	388%	260%	115%

Note: "a" refers to the parametric variation from 40% to 50% goal value; "b" refers to the parametric variation from 50% to 60% goal value.

CONCLUSION

Conclusions and Policy Recommendations

The delineation work is essential for the subsequent management of gold resource planning regions. In this study, the Voronoi diagram and buffer analysis were performed to calculate the spatial scope of the 7 gold resource planning regions that proposed in the National Mineral Resources Plan (2016-2020) and satisfies multiple objectives, including spatial agglomeration of mining rights, regional coordinated development, and guarantee the domestic supply. The scope from both resource exploitation (mining right-level) and management (administrative county-level) perspectives were delineated under 60%, 50% and 40% goal values. The results show that: (1) Zijinshan, Zhaoyuan-Laizhou and Xiaoqinling-Xiongershan are the best three planning regions to guarantee domestic baseline of gold resources; (2) with the increase of the goal value, the County-level administrative regions involved, the number of mining rights, and especially the planning region sizes all increase greatly, and their number increase with the goal value from 50% to 60% is more than that from 40% to 50% goal value, but their percentage increase is just the opposite.

Mineral resources management is an interdisciplinary subject of resources science and management science. In recent years, integration with economics, statistics, geography and other disciplines has become more common (Guo et al., 2016; Yokoi et al., 2018). Geographic theories, and statistic and spatial analysis methods can solve some problems in mineral resource management (Aroca and Atienza, 2011; Doraisami, 2015; De Souza Ramser et al., 2019). Mineral resources have obvious spatial properties. These spatial properties are the basis of mineral resource layout and partition management. Partition management is closely integrated with geography and follows the basic geographic theory. Compared with economics and statistics, there are fewer studies on the integration of geography and mineral resource management, and most studies on zoning are based on metallogenic theory. The spatial scope of gold resource planning regions is an exploratory study of the cross-fusion of mineral resources management and geography.

In terms of policy implications, firstly, this study can provide some reference for the Chinese government to select suitable spatial scope for gold resource planning regions. From the results, we can see that the higher the goal value, the larger the planning region size, the more the gold mining rights and county-level regions, which means more ecological environment impact cost (Liang et al., 2019), more land occupation and more management cost. For example, by comparing the results of gold resource planning regions at 60% and 50% goal values, although the former goal value is only slightly higher than the latter, the number of mining rights are 198 more, with 94,6247 km^2 areal increase, and 90 more county-level regions. The government may take the management cost and increase of ecological environment impact cost into consideration, and choose a suitable goal value to delimit scientific and reasonable spatial scope of gold resource planning regions.

Secondly, the results of this study can also provide reference for the differential management of gold resource planning regions. As Zijinshan, Zhaoyuan-Laizhou and Xiaoqinling-Xiongershan have the largest gold production capacities, and were exploited before the other planning regions, we suggest that the key of management policy in these three areas is to improve the level of large-scale development and promote conservation and circulatory use of resources. For example, the government may make some incentive policies for large-scale mining enterprises and inhibit small-scale mining activities that are with low-standard resource management and safety practice, and to define a minimal mining-scale for newly-built mines to increase the proportion of large and medium mines. Meanwhile, the mining technology standard in these three areas should be above that of other planning regions to reduce environmental impacts. For Southern Gansu and Zhenfeng-Pu'an, which have medium gold production capacities, the key management policy is to guarantee stable production by the mining enterprises. We suggest that the government to carry out some protective measures for mining enterprises in these two planning regions to maintain their current production, and to encourage geological exploration. For Pingjiang-Liling and Eastern Kunlun, which have the lowest production capacities, the key is to increase geological exploration and resource evaluation to find more gold resources, and safeguard these prospective areas from other land development activities.

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