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A novel understanding of land use characteristics caused by mining activities: A case study of Wu'an, China

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ABSTRACT

An idea that which zones are the main disturbed areas in mining cities and what are the exact impacts in space concerns re-use and optimal allocation of land. Current research mostly concludes that mining activities impact land use greatly, but there is no definite spatial range of disturbance. To find out the exact range, this paper sets up 12 gradients composed of mineral locations and 11 surrounding gradients with an interval of 3 km. And the "D-C-S" (Disturbance-Continuity- Sustainability) framework was then established to evaluate land use characteristics, including 9 indices in the three layers of disturbance, continuity and sustainability. Here, this paper adopted two approaches – transverse land use profiles and anomalous economic points – to test out the understanding of land use characteristics in mining cities. Our findings show that the areas surrounding mineral locations possibly play a more important role in land use structure and functions, designated to 0–9 km, especially 3–6 km away from mineral locations, where land needs more concerns about optimal allocation for future policy-making to improve the pattern, function and continuity.

1. Introduction

The procurement of environmental sustainability is a critical challenge for humanity due to world population growth and urban sprawl, induced by an increasing demand for base metals to produce industrial products and infrastructure (Kobayashi et al., 2014; Swenson et al., 2011). Defined by an abundance of economically accessible mineral resources, mining regions often undergo an abrupt and extensive change of land use (Bridge, 2004), causing environmental damage to land at all scales (Andrew, 2003) and also social conflicts (Preciado Jeronimo et al., 2015; Sudmeier-Rieux et al., 2015). Mining is considered as a temporary land use, and it is hard to forecast its possible disturbance accurately, in temporal and/or in spatial domain. Due to availability of minerals, rapid industrialization and government policies, land use becomes highly vulnerable and sensitive (Malaviya et al., 2010), as a significant consideration for mitigation of land degradation and sustainable land management (Barkemeyer et al., 2015; Cao, 2007). If the environmental impact of mining activities is not handled with a great concern, the inputs of human, physical, financial resources to land re-use and ecological rehabilitation may be doubled (Maryati et al., 2012). Therefore, the environmental issues induced by mining activities, especially in developing and mineral-supported countries, raise wide concerns all over the world.

The primary study in mining areas is focused on the transformation of land use types, mainly on macro-level. Both temporal and spatial magnitude of mining has a profound impact on formation of land use characteristics (López-Merino et al., 2014). With passage of time, mining processes alter natural surface worldwide, typically disturbed by the extraction, detachment, transportation and pileup of earth materials (Clark and Zipper, 2016) for mining sites and subsidiary facilities (Yang et al., 2003). Landscape memory was lost in the process of mineral extraction, only leaving the trace of mining or novel landscapes (McHaina, 2001; Skaloš and Kašparová, 2012). In consequence, land use change in mining areas are characterized by mining land's occupying other lands, with a sharp decrease of farmland, forest, etc. and serious land fragmentation

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(Djietror and Catherine, 2012; Duncan et al., 2009; Schueler et al., 2011). As a result of that, the pattern of disturbance-dominated land use may fluctuate widely over time in response to the interplay between disturbance and succession processes, caused by a combination of natural and human activities (Antwi et al., 2008). Here, human activities are also represented by recultivation and renaturation processes, an influential change on land use pattern (Larondelle and Haase, 2012). Year by year, the development of new land use, positive or negative, is eventually accelerated for sustainable establishment of new ecosystems in mined areas (Hüttl and Gerwin, 2005).

Land use characteristics are also shaped by spatial mining successions. In underground mining areas, land unaffected by mining influence decreases at the expense of the progressing subsidence basin, causing the redistribution of influences on land use (Marschalko et al., 2015). Similarly, surface mining does not only affect the land use in which it takes place, and pits have significant effects on the adjacent environment and land designations (Bangian et al., 2012; Svobodova et al., 2012). In other word, land use change is altered by a combination of mining and non-mining activities (Moran et al., 2013). However, compared with mining regions, land use is significantly different in surrounding non-mining regions (Sonter et al., 2014). The negative impacts of mining is not only land disturbance, but also off-site impacts, community displacement, etc., from mining regions expanded to surroundings in space (Hilson and Murck, 2000; Sánchez, 1998). Non-mining regions have relatively less influence directly by mining (Liu, 2011), but the lasting, transformative effects on land use and related economies are marked by mineral extraction (LeClerc and Keeling, 2015). Obviously, land use characteristics by mining are not only assigned to mining regions but linked with surroundings, by a way of economic transition, environmental pollution or social service, successionally (Bloodworth et al., 2009; Limpitlaw and Briel, 2014; Morrison et al., 2012).

Currently, widely used techniques and methods include remote sensing (RS), geographic information system (GIS) and land-use models. Time series RS images are applied to interpret land use change and habitat diversity in mining areas for a delineation of land use characteristics (Malaviya et al., 2010; Xie et al., 2007), usually representing different periods of mineral extraction, working or abandoned (Bell et al., 2001). Also, GIS has proven effective in characterizing land use to identify disturbance by mapping disturbance zones in ecosystems, quantifying their impact on biodiversity and detecting land cover changes over a period of time (Antwi et al., 2008). Models have been established for simulating and indicating some land use characteristics, e.g., a quantitative and practical index is used for simulating and indicating biodiversity (Kobayashi et al., 2014), and a number of single-index or multi-index models are proposed or applied to reveal land use pattern and ecological process at different scales (Li and Reynolds, 1994; Scullion et al., 2014; Xie et al., 2007). Generally, RS, GIS and index models play a key role in shaping land use characteristics by mining, in time-and/or space-scale, towards negative or re-positive designations of land use.

As mentioned above, the variation in land use characteristics is obviously changing with years and working surface of mining activities, but the mining regions are always taken as a core impact part for debates. The general law is summarized that mining activities has a drastic impact on land use by a negative way of excavation, occupation, damage, etc. and a positive way of revegetation and rehabilitation. Additionally, the disturbance by mining are being imposed to surroundings, though surface modification is varied with mining intensity and scope (Bi et al., 2007; Kusimi, 2015). Mining activity, mostly oriented by land use, usually takes place at minerals-exiting areas (Giriraj and Nidhi, 2010). The surrounding areas are suffering an enormous increase of land intensity, environmental pollution and other socio-economic activities, even towards a warning level of disturbance (Samanta, 2015), where the disturbance breaks down environmental, social, economic and political boundaries (Worrall et al., 2009). Obviously, the buffers have a good contribution to land use for biodiversity conservation (Kusimi, 2015). Following the current viewpoints but different from them in measurement, this paper hereby tries to reveal how land use characteristics change within and around mining regions in a quantitative and simulative way to select what zone/section is disturbed most. Considering a possible change of ideal concentric circles in land use and its reaction to mining, this paper generally assumes the proven mineral locations as basic zones and then creates a number of buffers covering the entirety of Wu'an, composed of two main mineral belts along the middle and eastern directions. As for the objectives, this paper tries to (1) establish a comprehensive index system for evaluating land use characteristics in mining areas, (2) select and simulate land use characteristics in mining areas, (3) and reveal the change of land use profiles.

2. Materials and methods

2.1. General situations of study area

Wu'an lies in the hinterland of the Zhongyuan Economic Zone in China, covering a surface area of 1819 km^2, located at 113°45′–114°22′E and 36°28′–37°01′N. It is high in the west and low in the east, with a small basin called Wu'an Basin in the middle. Wu'an is an important energy supplier in Hebei Province, rich in coal, iron, cobalt, aluminum and others, mostly extracted by underground mining. It also has rich tourism resources with a national geological park and the Xishimen Mine Park in the north (Fig. 1).

2.2. Data source

The primary data used in this study is from land use database, obtained in the year of 1996, 2005 and 2014. The land use database was obtained by human-computer interpretation technology and field surveying and then stored in GIS platform. The selected years represent the three periods of mining activities, divided by the turning point of economic development in 2005, when the GDP growth was doubled or even more (leading to an extremely fast increase), and also mining-oriented industrial GDP accounted for nearly 75% of the total (a historical maximum). According to the current land classification standard of China and actual research requirements, the entire area is classified into 8 major land use types, including cropland, orchard, forest, pasture, built-up land (here excluding industrial and mining land), industrial and mining land, undeveloped land and water body (Fig. 2) (Zhang et al., 2014).

2.3. Considerations for study framework

As generally known to us, negative impact of mining often decreases with distance to mining areas. Accordingly, a fluctuating change of land use is characterized by a certain curve and within a certain zone. Therefore, there two considerations are presented here.

- Firstly, land use is subjected to mining activities and spreading effects, but it is hard to refine the exact range and degree of impact at the city scale. Scale transition is a good key to open this locker, by classifying the entire study area into a number of small-scale zones. Then the total change of land use at the city scale is presented by the integration of accumulative changes of small-scale zones.
- Secondly, a mining city is suffering an interconnected impact of natural environment and human activities. Land use characteris-