

A review on anthropogenic geomorphology

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Abstract: With the continuous development of man's ability to reshape nature, human activities have become the third geomorphologic agent in the modern geomorphological process. Man-made landform is a landform unit characterized by human activities and is a result of synergizing human and nature geomorphologic agents under the physical geographical background. This article provides an overview on the major progresses in research on anthropogenic geomorphology from aspects like the origin of anthropogenic geomorphology, man-made landform agents and classification, man-made landform evolution and its influencing mechanism, map presentation of man-made landform, and environmental impact of man-made landforms. In addition, in the article, the future development of anthropogenic geomorphology is forecasted. It is pointed out that future studies on anthropogenic geomorphology should pay more attention to the following directions: construction of discipline system of anthropogenic geomorphology, material composition and morphological features of man-made landforms, spatial expansion process and development laws of man-made landforms, regional disparity and accumulative environmental effects of man-made landforms, and environmental management on man-made landforms and comparative analyses of relevant international management policies.

Keywords: anthropogenic geomorphology; the third geomorphologic agent; man-made landform evolution; urban anthropogenic geomorphology; man-made landform environmental management

1 Introduction

Geomorphology is a subject that investigates undulating landform on the Earth surface, with an emphasis on its origin, development, structure, agent and distribution (Chorley, 1985). With the socio-economic development and science and technology advancement, human's capability of transforming nature is strengthening and our influence on original terrains on the Earth surface is increasingly significantly. In some aspects, human has even exceeded the natural force at the energy level on transforming Earth's environment. Various anthropogenic geomorphological landscapes have been created on the basis of different natural

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terrains (Diao, 1993; Zhang, 1996; Li *et al.*, 2003). Developed on the basis of certain natural geomorphology, the artificial geomorphological landscape is an aggregation of a series of man-made landforms, which has distinctive features differing from the natural landscape and exerts a significant impact on the natural geomorphological process (Mu, 1990a; Li *et al.*, 2003). Therefore, anthropogenic geomorphology has become an important part in the study on modern geomorphology. To promote the construction of the disciplinary system of anthropogenic geomorphology and provide guidance for the anthropogenic geomorphological process in modern socio-economic construction, in the article we will make an overview on the disciplinary research progress, including the origin of anthropogenic geomorphology, artificial landform agents and classification, artificial landform evolution and its influencing mechanism, artificial landform mapping, and the environmental impact of man-made landforms.

2 Origin of anthropogenic geomorphology

The anthropogenic geomorphology appeared with the advent of mankind and generates an increasing influence on the Earth surface environment with enhancing degree of landform transformed by human activities (József *et al.*, 2010). Since ancient times, a considerable number of historic man-made landforms have emerged both at home and abroad. Throughout China's civilization, the most representative man-made landforms are the Great Wall and Beijing-Hangzhou Grand Canal. In addition, Dujiangyan Irrigation System, Fangong Seawall and Dagu Seawall also have an important historical status (Mu and Tan, 1990a). In considering world civilization, the pyramids in Ancient Egypt, the Hanging Garden in Ancient Babylon, the Asoka Pagoda and Taj Mahal in Ancient India are all typical examples of man-made landforms. Over the past two centuries since the Industrial Revolution in the 18th century, with the gradual improvement of social productivity, human has been constantly enhancing the capacity of reshaping and utilizing nature (Nir, 1983). Consequently, original geomorphologic landscapes have been transformed tremendously, and a variety of man-made geomorphologic landscapes with marks of human activities have been formed. Man-made landforms, such as artificial lakes, canals, large-scale dykes, lands reclaimed from sea, sub-sea tunnels, modern bridges, high-rise buildings, and underground constructions, etc., emerge endlessly, producing an increasingly profound impact on original geomorphologic landscapes on the Earth surface. The significant changes of the original geomorphology reflect constructions of agricultural terraces, road networks and other relevant infrastructures, and constructing artificial coastlines and reservoirs, etc. as well (Tsermegas, 2015). The constituent materials of man-made landforms, based on their sources, could be divided into three types: natural materials, human waste and artificial materials. Among the three types, the proportion of the artificial materials in forming man-made landforms is increasing continuously. This makes man-made landforms have completely different features from those of natural geomorphology (Mu and Tan, 1990a). It reflects that, apart from natural geomorphological units shaped by internal and external forces of the earth, there exist increasing geomorphological units constructed by anthropogenic geomorphological activities on the Earth surface (József *et al.*, 2010).

There is a long history of Chinese scholars studying on man-made geomorphology. For

instance, there are a lot of descriptions of man-made landforms from *Records of the Grand Historian* by Sima Qian from Western Han Dynasty, *Dream Pool Essays* by Shen Kuo from Northern Song Dynasty, *The Travels of Xuxiake* by Xu Xiake from Ming Dynasty, and the geography monograph “Liu Ting Yu Di Yu Shuo” by Sun Lan from the early Qing Dynasty, and especially Sun Lan has pointed out the anthropogenic action in the geomorphological process clearly (Mu and Tan, 1990a). Abroad, research on anthropogenic geomorphology could be traced back to the early 20th century, initiated with a series of publications addressing man-made landforms. Woeikof (1901) discussed the natural vegetation removal, irrigation and drainage engineering construction and natural geomorphologic environmental damage due to urban development (Mu and Tan, 1990a). Sauer (1931) pointed out that we must consider human activity as a kind of direct geomorphologic agent because it can and has changed the denudation and deposition situation on the Earth surface. In 1955, the international conference themed “Man’s Role in Changing the Face of the Earth” was held in Princeton, USA, indicating that studies on anthropogenic geomorphology had drawn widespread attention in the academia (Gregory and Walling, 1981). Since then, *Man as a Geological Agent* by Jennings (1966), *Human Shape the Earth* by Brown (1970), *The Human Influence on the Natural Environment* by Detwyler (1971), and *The Earth and Human Events* by Collier (1972) were brought out as representative research results on anthropogenic geomorphologic studies (Mu and Tan, 1990a). In 1983, the book *Man, A Geomorphologic Agent: An Introduction to Anthropic Geomorphology* published by Nir (1983) marked that the Anthropogenic Geomorphology as an independent discipline was officially separated from Geomorphology. The 124th annual meeting of Geological Society of America (GSA) held in 2012 centered on “Anthropogenic Geomorphology: The Surface Effect of Past and Current Human Activities”. Through practical investigations of multiple temporal-spatial scales and comprehensive theoretical reviews, the evolution features of the Earth surface under the influence of ever-increasing human activities were better understood. The outcome of the conference was published in the journal “Anthropocene” as a special issue (Jefferson *et al.*, 2013). This issue not only stressed traditional research, i.e., the influence of human activities on geomorphologic shape and process, but also emphasized the accumulative effectiveness of human activities in time and space. It can provide references for decision making in future geomorphologic landscape management, and represents an important development direction of the current anthropogenic geomorphologic study.

Anthropogenic geomorphology is a discipline that investigates relief terrain formed by human activities on the Earth surface, with an emphasis on its material constitution, origin, evolution and distribution laws (Nir, 1983). Taking man-made landforms characterized with human elements as main research object, anthropogenic geomorphology reflects the influence of human activity, as the third geomorphologic agent, on modern geomorphological process (Hu and Wang, 2010). Mu and Tan (1990a) firstly put forward the “Anthropogenic Geomorphology” concept in China. They explored in detail the development, implication and impact factors of anthropogenic geomorphology and the features of man-made landforms in their book entitled *A Preliminary Study of Anthropic Geomorphology*, which plays a leading role in the development of China’s anthropogenic geomorphology. Ursu *et al.* (2011) argued that man-made landforms are the important traces left on the Earth surface by needs of social, economic and cultural developments under the leading of science and tech-

nology development of human society.

To sum up, early anthropogenic geomorphological studies emphasized the definition of concepts, the influence of human activities on topography, creatures and disasters on the Earth surface, and the formation of man-made landforms and their relationship with the environment. Although the concept of anthropogenic geomorphology has been put forward, the subject is still a new interdisciplinary and fundamental theoretical research and empirical studies associated with this subject are still very weak. Undeniably, human activity is a quite important factor in the formation and evolution process of modern geomorphology. On one hand, it can accelerate or delay the course of geomorphological process; on the other hand, it also can create new geomorphological phenomena. Therefore, the rise of anthropogenic geomorphological investigation has a quite obvious driving effect on the studies of modern geomorphological process.

3 Man-made landform agents and classification

3.1 Man-made landform agents

Although the participation of human activities in landform evolution has had a long history, it is especially active in modern times. With the deepening of the Industrial Revolution, accelerating process of urbanization and constant socio-economic development, the modern landform evolution process is no longer a pure natural process, but a process deeply marked by human activities (Li *et al.*, 1994). Human activity has become the third geomorphologic agent besides the internal and external natural forces (Zhang, 1990). Yan Qinshang, a famous geomorphologist in China, once pointed out that the development of natural landforms is mixed up with factors of human activities, which is an important part in the development and evolution process of natural landforms, either speeding up or slowing down the process (Yan, 1985). The synergistic effect of natural forces and human activities has become a key factor to modern landform evolution and development, which attracts the attention of the geomorphology community to the third geomorphologic agent (Mu, 1990; Diao *et al.*, 2000).

Man-made landform agents mainly refer to the forces that directly or indirectly change natural landform processes in human life and production (Shi, 2009). It is worthy of noting that man-made landform agents are the artificial agents that are imposed to natural landforms on the basis of natural landform agents. This kind of geomorphologic agent varies with the purposes and functions of man-made landform constructions. The geomorphologic agent can be produced by either direct and purposeful human activities, or indirect or unintentional ones. Thus its effect on the whole anthropogenic geomorphological process can be divided into three types: direct, incidental, and unintentional (Nir, 1983). Based on the effect on man-made landform construction, the man-made landform agents can be divided into types of artificial weathering, artificial erosion, artificial transference and artificial accumulation (Hooke, 1994; Yang, 1998). Artificial weathering refers to the further exacerbation of earth surface material compositions weathering rate caused by human socio-economic construction, both physically and chemically. Human activities like tunnel projects, mining and blasting may result in mechanical disintegration or stress-release crack, aggravating the physical weathering process of surface material compositions. And the emission of human

“three wastes” may intensify the chemical weathering (Zhou *et al.*, 2013). Artificial erosion includes direct and indirect erosions (Hooke, 1994; Yang, 1998). First, human social and economic constructions directly act on the Earth surface and cause surface erosion. The rate and strength of this kind of erosion are always much greater than those of natural erosion (Chin *et al.*, 2014). Second, the damage of surface environment caused by human activities triggers or increases natural erosion within the area of activities. Artificial transference mainly refers to the transportation and migration of surface materials made by purposeful human activities like infrastructure constructions by means of conveyance (Hooke, 1994; Yang, 1998). Its significant difference from natural transference is that the transportation of materials takes place according to human’s will and needs. Comparatively, the natural transference is generally conducted either from high to low position or from upstream to downstream under the influence of natural forces, and also in this process, the moving capacity is reduced with distance constantly. Artificial accumulation also includes direct and indirect accumulations (Hooke, 1994; Yang, 1998). The former refers to the geomorphologic accumulation made by man’s purposeful, direct transportation, while the latter refers to the geomorphologic accumulation caused by changing natural force conditions due to human activities.

Therefore, man-made landforms are created under the direct or indirect effects of human activities, which include a variety of human actions, such as construction, digging, erosion and deposition (Yang, 1983; Yang and Li, 2001). These actions jointly shape man-made landforms on the Earth surface and constitute the man-made landform agent system.

3.2 Man-made landform classification

With the enhancement of human’s ability to reshape nature, the number of types of man-made landforms keeps increasing. According to different research objectives and principles of classification, there are different criteria for man-made landform classification. In accordance with material erosion or accumulation situation, man-made landforms caused by such human activities as urban-rural construction, agricultural production, engineering construction and resource exploitation can be classified into the two types of man-made accumulation landforms and man-made erosion landforms (Yang, 1998). There is not only accumulation or erosion landforms shaped through human activities like building, repairing, digging or dredging in order to satisfy the needs of human production and life, but also waste accumulation landforms created by accumulating industrial and domestic wastes and household garbage and so on. Certainly, the actual man-made landforms are more organic integration of the both. For instance, the Three Gorges Project involves not only excavation and erosion of the bedrock on dam base but also the construction and accumulation for dam rebuilding. The seawall construction in tidal flat includes both the excavation of sediments on tidal flat and the accumulation of soil or stone seawall. In the construction of urban man-made landform, materials like cement, steels, timber, sand and stones create the accumulation landform, namely, the city. Meanwhile, erosion landforms like sand pits, gravel pits and stone pits are formed in surrounding areas through excavation (Zhang, 1990).

Based on the actual needs of human social and economic construction, Ma (2008) classified man-made landforms into types like urban man-made landform, transportation man-made landform, water conservancy man-made landform, farmland man-made landform,

mine man-made landform and oilfield man-made landform, etc. She believes that globalization facilitates the homogenization of man-made landforms in different countries, which is the man-made landform construction dominated by rational thinking. The organic integration of various man-made landforms constitutes regional man-made geomorphological landscape (Li and Liu, 1990). Man-made terrains and landforms are of great significance for regional planning and construction, transforming of urban-rural layout, and the development of tourism and so on (Ma, 2008). Based on the principle of morphological classification, we can divide man-made landforms into linear man-made landform, planar man-made landform and three-dimensional man-made landform (Kuang, 1990). Man-made landform possesses environmental function, economic function and value of landscape aesthetics (Chen and Wu, 1993). In accordance with functional morphology, man-made landforms can be classified into nine types, including urban-rural construction morphology and industrial morphology, etc., and the nine types can be further divided into man-made accumulation subtype and man-made excavation subtype based on the causes of formation (Ma, 2008). In fact, this application orientated classification principle does not break the limitation of land use classification.

Urban man-made landform, as a regional type of man-made landform, has three subsystems, including natural landform, man-made landform, and natural and artificial mixed landform. In the 1990s, geographers of the older generation conducted a preliminary study on the classification system of urban man-made landform. They proposed a principle of shape genesis and utility for urban landforms classification (Zhang and Chen, 2000a) and classified urban man-made landforms into two types, the direct and the indirect (Zhang, 1990). Furthermore, they explored the structural relations between constituent parts of the urban landform system (Pan *et al.*, 1989) in order to establish a theoretical foundation for the construction of various classification systems. As man-made landform usually manifests its eco-environmental features due to forming a large amount of impervious surface. Meantime, various individual man-made landforms combine together to constitute diversified regional man-made landforms. Therefore, it is more suitable to adopt a man-made landform classification system based on the classification principle of ecology and morphology (Pan *et al.*, 1989). By referring to the classification method of traditional geomorphology, a three-level classification method of urban man-made landforms based on landform name, morphological feature, and function and utility, respectively, has been adopted, which promotes the research on urban man-made landform classification (Zhou *et al.*, 2007).

4 Evolution of man-made landform

4.1 Anthropogenic geomorphological process

Traditional geomorphology believes that geomorphological process includes processes of the internal and external forces of the Earth (Chorley, 1985). With the development of society and economy and the intensified efforts of human to remold the Earth surface, anthropogenic geomorphological process has gradually become an important agent in modern geomorphological process. The anthropogenic geomorphological process significantly influences geomorphological development along with the Earth's internal and external forces.

And the former has even exceeded the latter in influencing regional geomorphological process (Diao, 1990). Although man-made landform has a short history and the earliest one appeared just thousands of years ago, man-made landforms are formed at a fast speed. Their formation may only take several decades, a few years or even several days (Mu and Tan, 1990a). The life span of man-made landforms is affected by multiple factors, including natural, humanistic, economic and political ones (Rózsa, 2007). Man-made landforms are formed on the basis of natural landform's processes. Therefore, they are deeply influenced by natural environments, such as erosion, denudation, dissolution and earthquake, and, meanwhile, further intervened by human activities themselves.

Anthropogenic geomorphological process is the process of human activities acting on and influencing the geomorphological environment (Zhang, 1990). Since there are direct and indirect impacts of human activities on geomorphological environment, the anthropogenic geomorphological process can also be either direct or indirect (Zhang, 1990). The direct geomorphological process refers to the process, in which human activities directly reshape the Earth surface environment and produce various new geomorphological landscapes. After the formation of man-made landform, the man-made landform itself and human activities, which rely on it still continuously influence the material flow and energy flow in the geomorphological environment, and thus further change the strength and direction of the natural geomorphological process. This process is called the indirect geomorphological process (Zhang, 1990). Direct geomorphological process consists of accumulation process and denudation process. Although the indirect geomorphological process does not act on geomorphic environment directly to produce new landforms, it is a more complicated process and has more extensive effects on geomorphic environment than the direct one.

Anthropogenic geomorphological process, especially the direct one, is irreversible (Mu and Tan, 1990b). The direct geomorphological process usually creates new and relatively independent man-made landforms by processing and reshaping original natural landforms. Such new man-made landforms are jointed with natural landforms in a natural geomorphological system. In anthropogenic geomorphological process, the changes of natural geomorphic environment are irremediable and irreversible. For example, in a project of blasting mountains to build a city, the leveled mountains cannot be restored and the newly built city cannot be moved.

As urban regions are the most active areas of human activities (Cooke *et al.*, 1982). The process of urban human activities influencing geomorphic environment is the urban anthropogenic geomorphological process (Zhang, 1990), and thus the urban anthropogenic geomorphological process is a key part in anthropogenic geomorphological process research (Cooke *et al.*, 1982). The urban geomorphological process also includes the direct and indirect processes (Zhang, 1990; Szabó, 2010). The direct urban geomorphological process can be divided into denudation (damage) process and accumulation (construction) process. Specifically, the denudation process may be further classified into digging, flattening, slope cutting, and excavation processes, and the accumulation process may also be classified into constructing and repairing, stacking, and landfill processes, etc. (Douglas, 1983). The indirect urban geomorphological process is a formation process of urban natural landforms affected by the geomorphologic agents of environmental impact factors after urban transformation (Cooke *et al.*, 1982).

4.2 Urban man-made landform evolution

Compared with natural landforms that take a long time for formation and evolution, the development and evolution process of man-made landforms is relatively short. In the early agricultural society, man's capacity of reshaping natural landforms was quite limited. The man-made landforms were just simple and crude dwellings and cultivated lands, etc. Man-made landforms at that time were very limited no matter in quantity or size, and were abandoned with human migrations (Wang and Pu, 2000). With the advancement of agricultural production technology and the formations of ancient Babylon, Egyptian, Indian and Chinese civilizations, the distribution range of urban and rural settlements and agricultural landforms kept enlarging. And the development of other kinds of man-made landforms like road network was also accelerated continually (Zhang, 1990). It is worthy of mentioning that the research on urban man-made landforms outshines others in the research field of man-made landform evolution.

With the continuous expansion of city size, urban man-made landforms also experience constant formation, expansion and evolution. City, as the region where human activities are most concentrated, is most strongly influenced by human activities. Meanwhile, it is also the largest distribution area of man-made landscapes on the Earth surface. The research on the formation and evolution of urban man-made landforms must be combined with the evolution of urban spatial structure to explore the development pattern and law of man-made landforms in urban areas. Corresponding to urban spatial evolution, the formation and evolution of urban man-made landforms is of an ordered process (Huang and Zhu, 1996), which can be divided into three stages: dilation, renewal and diffusion, and differential renewal and diffusion (Mu and Gao, 1990). In the early formation of a city, man-made landforms such as buildings are arranged in dot distribution in places with convenient transportation and rich resources, then extended outward continuously and developed into landforms of planar distribution. When the city expands to a certain size, influenced by terrain and transportation, urban man-made landforms experience obvious internal renewal like old city reconstruction. Meanwhile, the density and single size of urban man-made landforms keep increasing. After that, blocks with favorable conditions in each region are gradually formed and united together. The spatial distribution range of urban man-made landforms also extends continuously (Cooke *et al.*, 1982). On this basis, by combining the development history of Dalian and the characteristics of its development orientation, Li *et al.* (2003) divided the evolution of urban man-made landforms in the city area into four periods. They are single-core diffusion period, U-shaped extension period, annular zonary renewal and diffusion period, and multicore radiation-zonary development period. The rapid expansion of the urban space in Dalian directly led to the expansion of urban man-made landforms. From the perspective of horizontal morphological expansion, growth patterns of urban man-made landforms from CDB (central business district) to surrounding areas include concentric sprawl, local fan-shaped expansion, gallery-type radiation, enclave-style growth and agglutinating fill (Liu, 2004). At the same time, urban man-made landforms also show a typical characteristic of vertical growth (Li, 2004). This shows the vertical expansion of man-made landforms in CBD area that presents different time sequence and growth patterns. In addition, the vertical growth of urban man-made landforms has significant periodical characteristics (Chang, 2004). Certainly, the horizontal expansion and vertical growth of urban man-made land-

forms may exist simultaneously and finally constitute overall urban man-made geomorphological landscape patterns.

Certainly, the evolution of urban man-made landforms includes not only the expansion of landforms, but also their shrinkage and disappearance, such as urban demolition and old city reconstruction. These processes also reflect the renewal and recombination of urban man-made landforms as well as their evolution during urban development. It thus can be seen that the essence of evolution of urban man-made landforms lies in the reconstruction, renewal and optimization of urban geomorphic structures (Zhao, 2007).

5 Influencing mechanism of man-made landform evolution

5.1 Influencing factors of anthropogenic geomorphological process

Man-made landforms are geomorphic units formed on the basis of natural landforms. Therefore, anthropogenic geomorphological process cannot be separated from natural landform basis. With the increasingly strong needs for reshaping nature and the gradual improvement of social productivity, conscious or unconscious human production practices and activities are heavily influencing the evolution process of modern Earth surface geomorphic system, which prompts researchers to enhance the study on evolution factors of geomorphology. Especially, the role of human activities in modern geomorphological process has caught a great attention (Carol and Harden, 2014). For examples, port site selection needs taking into consideration the coastwise water depth and hinterland conditions (Li and Jiang, 2010); mud flat inning should be conducted in open silting tidal flats (Chen, 2000); and as for city location selection, stable geological structure and relatively flat terrain are necessary (Dong, 2004). However, with the continuous development and effect of human society on environment and intensified degree of environmental reconstruction, the strength and distribution scope of anthropogenic geomorphological process also keep increasing. Science and technology advancements are reducing the influence of natural landform basis on man-made landform construction. Thus, socio-economic factors in human society have become important influencing elements in the anthropogenic geomorphological process. After analyzing the effect intensity of human activities in 37 countries on local geomorphic environment, Nir (1983) believes that population growth, science and technology advancements and the improvement of socio-economic development level are the key factors that affect anthropogenic geomorphological process.

From the emergence of human being to the end of Paleolithic Age, from the Neolithic Age to the period before Industrial Revolution, and from Industrial Revolution to modern times, population growth showed corresponding logarithmic curves. It proves that the three periods of population growth correspond with the three major technical revolutions. There is also an obvious correlation between population growth and socio-economic development (József, 2010). The increasing human demands and continuous improvement of living standard also broaden the range and increase the degree of human activities' influence on natural geomorphological process constantly. In the Early Holocene Epoch 12,000 years ago, while human lived on a primitive hunting, they started to consciously collect wild wheat for crop cultivation. Their activities altered the surface environment, but the influence on surface environment was limited spatially and temporally. Since the beginning of agricultural soci-

ety 5000 years ago (József, 2010), the development of irrigation agriculture, the use of metal tools, the spread of plough and wheelbarrow, the construction of road network, and the utilization of wind energy and hydraulic resources have enhanced the spatial and temporal effects of human activities on geomorphic environment. Since the first Industrial Revolution in 1870 and the second in 1950, the use of steam engine, the development of industrialization, the growth of iron and steel industry, the construction of railway network, and the use of electric energy and internal combustion engine have enabled human to exert long-lasting influence on the geomorphic environment in a larger range. The third Industrial Revolution symbolized by the invention and application of atomic energy, electronic computer, space technology and biological engineering since the 1950s has been making the influence of human activities on the Earth's surface environment permanent and even irreversible. Before Industrial Revolution, the influence of human activities on geomorphic environment grew slowly, which was mainly indirectly resulted from agricultural activities. However, the Industrial Revolution completely changed this pattern of growth. That means, with the exponential increase of population, the total amount of surface material excavated by man shows a sharp rise (József, 2010). Over the past 500 years, the excavated and moved surface materials could be heaped into a mountain with a size of $100 \text{ km} \times 40 \text{ km} \times 4 \text{ km}$. Since the excavating speed is still increasing constantly, the size of the "heaped mountain" is predicted to double in a century (Hooke, 2000). All the facts addressed above demonstrate that socio-economic development and science and technology advancements are the important factors that lead to the acceleration of anthropogenic geomorphological process.

5.2 Influencing mechanism of urban man-made landform evolution

Urban regions are the most typical areas of anthropogenic geomorphological process and geomorphic evolution. Urban man-made landform evolution is an important area in studying anthropogenic geomorphological process and thus is of great significance for exploring anthropogenic geomorphological process (Zhang, 1990; Li *et al.*, 2003). Urban expansion results from integrative action of multiple factors. The factors that dominate urban expansion correspondingly change at different stages of urban development (Li, 2007). Therefore, urban man-made landform evolution is also the result of synergizing multiple factors. The influencing factors of urban man-made landform evolution have received considerable attention since the appearance of the cities (Zhou, 1995).

The basic roles of urban geological and geomorphological conditions, geomorphological processes of different properties and strengths, state policies, urban planning and the level of economic development in the evolution of urban man-made landforms have been widely accepted (Chen and Wu, 1993; Li, 2007). Natural geology and geomorphology are the primary limiting factors for urban man-made landform evolution (Li, 2003). The urban geomorphological process based on natural geological and geomorphological conditions emphasizes the fundamental influence of natural geographical conditions on urban man-made landform development and evolution. The last two factors are human influencing factors that produce a decisive effect on the spatial layout of urban man-made landforms. They embody the characteristics of urban man-made landform construction, such as orderliness, foresight, and continuity (Chen and Wu, 1993; Li, 2007). There is a certain correlation between the speed and scale of urban man-made landform development and urban economic growth

(Zhou, 2006). Based on the obvious coupling relationship between urban man-made landform development characterized by a response model of man-made landforms to urbanization and the progress of urbanization, the development law of urban man-made landforms is clarified under the influence of urbanization (Li *et al.*, 2005). The effect of urban population change on urban man-made landform evolution is mainly reflected by the relationships between population growth and construction area and building height. Specifically, with the growth of urban population, the construction area of urban man-made landforms increases correspondingly. However, the relationships between population distribution and construction area in central urban areas and suburbs are inconsistent. Meantime, urban man-made landforms also respond to the population growth through raising the height of buildings (Li, 2003; Zhang and Li, 2007).

6 Map representation of man-made landform

Like natural landforms, man-made landforms also need to be directly presented with their distribution, evolution and law of development in a form of map. Man-made landform map is a means of studying the strength and space distribution of anthropogenic geomorphological process (Pan *et al.*, 1989; Verstappn and Diao, 1989). It is also a basic map used in urban planning and socio-economic construction management (Li, 2004). Therefore, the compilation of man-made landform map needs to rely on traditional geomorphological maps, and heavily draws on compiling methods and thoughts of traditional geomorphological mapping.

The compilation of man-made landform map requires using unified principle of man-made landform classification and a legend system (Sha and Li, 1988). Only is a unified man-made landform classification system established, can the man-made landform map be better applied in urban planning and socio-economic construction management. By referring to the principle of general geomorphology, combining absolute elevations with relative elevations and integrating forms of various undulating man-made landforms, man-made landforms can be divided into several types, including man-made “mountain”, “hill”, “basin”, “valley”, “terrace”, “isolated peak” and “isolated hill”, etc. (Li, 2004). In addition, the compilation of man-made landform map also requires a unified legend system in order to facilitate comparative analysis of different regions (Sha and Li, 1988). The development of information technology and computer-aided mapping tool provide technical support to the compilation of man-made landform map (Li *et al.*, 2005).

Since city is a concentrated area of distribution of man-made landforms, the distribution, evolution and law of development of urban man-made landforms are fairly complicated. We can effectively present the distribution and spatial evolution characteristics of urban man-made landforms by compiling urban man-made landforms maps. Many scholars have made effective exploration in urban man-made landforms mapping since the 1980s (Sha and Li, 1988; Diao, 1993; Zhang and Chen, 2000b; Li *et al.*, 2003; Li *et al.*, 2005). The compilation of an urban man-made landform map, adopts the classification principle, which takes morphological division as a basis and combines morphology with the cause of formation (Li and Liu, 1990). Then further refer to the differences of man-made landform characteristics, different line or area symbols are superimposed on natural landforms. Next the types of ur-

ban landforms are clearly named after comprehensive consideration of various factors. In this way, not only can the distribution profile and morphological assemblage characteristics of urban natural and man-made landforms be clearly presented, but the detailed structure, cause of formation and constituent materials of various landform types can also be specified.

In recent years, researchers of urban man-made landforms have made relatively systematic explorations in the field of urban man-made landform mapping. For instance, they used Surfer 7.0, MapInfo and MapBasic etc. software and tools to draw series maps of urban man-made landforms (Li, 2004; Li *et al.*, 2005), including contour map, profile map, relative height map and accumulation index diagram of urban man-made landforms. All of these maps reflect the development situation and evolution law of urban man-made landforms. In this way, they achieved the goal of showing characteristic information of urban man-made landforms via maps. Since urban man-made landforms are the geomorphic units formed on the basis of urban natural landforms, they are embedded in urban natural landforms in terms of certain laws. Therefore, the urban landform map that combines urban man-made landform with natural landforms has a greater value to practical application. The urban landform map usually includes a basic natural geomorphological layer represented by even color, artificial geomorphological layer by area symbols, and a layer of necessary geographical elements by a variety of colors and shape symbols (Chen, 1992).

Considering the present research situation of modern Chinese landform mapping (Yin, 1988), the appearance of urban man-made landform series maps is of great significance. On one hand, this is a pioneering study of urban man-made landform mapping, which learns from the mapping system of traditional geomorphology. On the other hand, it has taken a significant step in the compilation of urban man-made landform maps along the path of standardization and normalization. Besides, it provides with new research tools for in-depth quantitative studies on urban man-made landforms and explores a new direction of research on urban anthropogenic geomorphology. Of course, the premises of mapping urban man-made landforms are the processes of the extraction of urban man-made landform information, the look-up of historical data and the measuring of man-made landform information, which are related to the process of information quantification of man-made landforms and the extraction and verification of topographic feature values as well. Thus, there are many follow-up problems to be solved about information quantification to draw man-made landform maps accurately.

7 Environmental influence of man-made landforms

As man-made landform construction increases the destruction on the Earth surface and reduces its resistance, the relative equilibrium between landform and geomorphological process is disturbed and even broken. This increases the sensitivity of geomorphological environment to variations and reduces its sustainable availability and its resilience to bearing variations (Diao and Cao, 1996; Ellis and Ramankutty, 2008). At present, anthropogenic influence is ubiquitous. Anthropogenic geomorphology should not only study the patterns of how human changes natural landforms and geomorphological processes but also explore how to change people's mode of action so that the geomorphological landscape resources can be better utilized through positive and negative feedbacks (Chin *et al.*, 2014). Although

early human activities are often ignored, their influence lasts till today. Present urban and rural development and the formation of corresponding man-made landforms can be understood as the extension of the influence of historical human activities on geomorphological environment (Bain, 2012). Early studies on the environmental influence of man-made landform mainly focused on the effects of human activities on river system and other geomorphological landscape processes (Thomas, 1956). For examples, the influence of dam construction on channels, water and soil loss caused by deforestation, and soil erosion resulted from agricultural production can be understood as typical cases, in which human, as a geomorphologic agent, shape man-made landforms (Jefferson *et al.*, 2013). By building the two-dimensional simulation model of riverbed terrain, Kukryul *et al.* (2010) evaluated the impact of artificially changed riverbed landform on the habitat of aquatic organisms. By investigating artificial habitat structure, Gulotty (2015) believes that the utilization of the artificial habitat structure is conducive to increasing the complexity of habitats and provides organisms with shelters. This is the latest research result of the influence of man-made landforms on riverbed landform and bio-distribution. It is also a successful example that man-made landforms are in harmony with the ecological environment.

Using the data offered by the Food and Agriculture Organization of the United Nations (UNFAO) since 1960, Hooke *et al.* (2012) estimated the geomorphological changes over the Earth surface, caused directly or indirectly by human infrastructure constructions, and their results demonstrate that 53.5% of land area on the Earth surface has been affected by human activities and shaped into man-made landforms to some extent. Wohl (2013) pointed out that the influence of anthropogenic geomorphological process exists everywhere even in such nature reserves as national parks and forests that we believe are not disturbed.

The intermittent deposition and undulation caused by man-made landform construction is defined as “deposition of human remainders” (James, 2013). This kind of deposition, as a historical mark, can be found in many geomorphological landscape patches. The deposition of human remainders can not only describe the methods that human uses to change sediment flux, but also connect the geomorphological landscapes at different spatial-temporal scales. The environmental influence of man-made landform can be divided into direct and indirect ones. The former directly changes natural geographical environment through man-made landform construction, hence resulting in direct changes of natural landforms (Diao and Cao, 1996). This kind of influence is particularly apparent in urban areas and coastal zones where man-made landforms are widely distributed. Different from the direct change of man-made landform process to the surface environment, the indirect environmental influence usually needs the aid of modern technological means for monitoring. The indirect environmental influence of man-made landforms may act on local micro-climate, sedimentary environment and hydrologic process, etc. (Zhang, 1998; Mann *et al.*, 2013; Mattheus and Norton, 2013).

In city areas, man-made landform construction, especially the hardening of the Earth surface, changes the properties of the underlying layer, produces urban heat island effect, and leads to gradual increasing of urban temperature and decreasing of wind speed, thus influencing the urban micro-climate (Zhang, 1998). Sediments in the reservoir record the influence of human activities on sediment transportation. Hence, by combining reservoir sediment record with the energy model of sediments in a modern river basin, we can better evaluate the periodical characteristics of regional population changes, strength of human

activities, and man-made landforms in certain periods. At smaller scales, sediment records and erosion models may be used in studies on the influence of man-made landform construction on erosions in urban forest zones. The urban forest zones that account for 30% of American urban areas have a much higher erosion rate than other forest areas (Mattheus and Norton, 2013). The high erosion rate is caused by the fact that the impervious surface formed in the urban infrastructure construction process aggravates rainstorm erosion or deforestation remainders reduce the anti-erosion ability of the forested slopes.

In coastal zones, the man-made coastal landform replaces the natural one, which changes the process and law of evolution of landforms and reshapes the geomorphic structure nearby, resulting in changes of material structure and geomorphic characteristics and leading to overall transition and even deterioration of the coastal environment. Relevant influences include the changes of erosion and deposition tendency of coastal landforms, the functional degeneration of tidal wetlands, the expansion of marine pollution scope, and species reduction, etc. (Yang, 2003; Ma *et al.*, 2006). The blindness and irrationality of coastal man-made landform construction are always the most important reasons why man-made landform construction damages the coastal environment. For example, the irrational reclamation and dam construction may aggravate seawater intrusion, sediment deposition in estuary and other environmental issues in coastal areas (Sun *et al.*, 2011). Particularly in estuarine delta areas, man-made landform construction changes the transportation process and tendency of sediments (Wang *et al.*, 2004) and thus influences the development process of local natural ecology there (El Banna and Frihy, 2009). As a result, the disturbance and impacts on the estuarine ecological system become apparent, and ecological disasters are getting serious (Cong *et al.*, 2010). However, not all man-made landform constructions cause environmental and ecological destruction and some can also bring in great ecological values. For example, the ecological framework design of multi-functional artificial structure is valuable to present and future urbanization development in coastal zones. It can not only reduce the negative ecological influence of oceanic urbanization, but also improve the functions of ecological services. This is a useful exploration on the man-made landform construction in coastal areas (Dafforn *et al.*, 2015).

Therefore, quantitative analysis is critically important to the study of the indirect influence of man-made landforms. Considering the diversity of indirect influence of man-made landforms, it may be a good choice to utilize remote sensing and GIS technologies and interdisciplinary knowledge to conduct coupling research. Through the coupling research, we can not only better explain the influence of man-made landform constructions in the past and at the present but also predict the future landform and geomorphological process produced by increasingly intensified interactions between human activities and the Earth surface (Jefferson *et al.*, 2013). It is commonly believed that to address the increasingly complicated relationships between human and landform, it is necessary to introduce new theories and methods. This will heavily stimulate research on how the Earth surface evolves (Harden *et al.*, 2014).

8 Prospect of anthropogenic geomorphological research

Man-made landforms have existed for a long time. In spite of the short history of systematic

research on man-made landforms, man-made landforms have already attracted the attention of the academia due to their practical application value and dramatic reconstruction they bring to natural landforms. However, the research objects, content, methods, and theoretical systems still need to be further demonstrated, and anthropogenic geomorphology has not been widely accepted by the academia. Therefore, at present, it is urgent to refer to research achievements of relevant disciplines and modern geographic information technology, improve the ability to cognize man-made landforms, and unearth the vital force, subject characteristics and significance of anthropogenic geomorphology. Furthermore, the recognition of anthropogenic geomorphologic theories in the other relevant disciplines and fields, such as geomorphology, environmental science, and urban planning should be raised, thus promoting the joint development and advancement of interdisciplinary studies. The future studies of anthropogenic geomorphology should take man-made landforms as the basis, and center on their relevant properties. In-depth explorations should be carried out from such aspects as structure, feature, influencing factor, and law of development of single landform. Then we connect external artificial elements with natural geomorphological background, and integrate single landform unit into the overall environment to explore relationships between different factors. Thus, we can better understand the evolution process of man-made landforms and their environmental effects and grasp the law of their evolution in order to serve urban and rural planning and socio-economic construction. In the future, the following research topics should be given special attention:

(1) Discipline system construction of man-made landforms

Although research on anthropogenic geomorphology has obtained significant achievements and made certain contributions to the urban and rural construction and socio-economic development, this subject still lags behind socio-economic construction practices both in theoretical study and practical application, which slows down the construction of the discipline system of anthropogenic geomorphology. Therefore, the emphasis should be laid on research on theoretical study and approach system in the future. Besides, anthropogenic geomorphology, an interdisciplinary of natural science and humanity, must break the research limit of geomorphology and seek out new research perspectives. The beneficial contents of demography, resource science, environmental science, urban planning, civil engineering, architecture, management science and other subjects should be assimilated and transformed into organic components of anthropogenic geomorphology. Meanwhile, anthropogenic geomorphology should develop concepts and theories different from natural geomorphology in order to establish its own theoretical system. Thus, anthropogenic geomorphology will be verified and widely recognized as an emerging branch of regional geomorphology (Chin *et al.*, 2014). Although studies on urban anthropogenic geomorphology and coastal anthropogenic geomorphology have yielded certain achievements, the classification system of branch subjects of anthropogenic geomorphology remains to be established.

(2) Material composition and morphological feature of man-made landforms

The constituent materials of man-made landforms have characteristics different from natural landforms. In addition to natural substance, the constituent materials of man-made landforms also include human waste and human subjective products, and the latter two have taken an increasingly larger proportion in the constituent materials of man-made landforms (Mu and Tan, 1990a). With the science and technology advancement, the variety of human

waste and subjective products that constitute man-made landforms keeps growing. In-depth studies on their influence on the anthropogenic and natural geomorphological processes are urgently needed. Besides, the differences of constituent materials cause great differences in the single scale and morphological feature of man-made landforms shaped in different periods. Therefore, the relationship between the material composition and morphology of man-made landforms should be explored.

(3) Spatial expansion characteristics and development law of man-made landforms

The research on anthropogenic geomorphological process is a basis of analyzing spatial expansion characteristics of man-made landforms in a certain period. Hence, anthropogenic geomorphological research should 1) discriminate the internal and external force system of man-made landforms in different periods, 2) analyze the functioning time of internal and external geomorphologic agents, 3) clarify their influence on the spatial expansion of man-made landforms, and 4) explore the law of development of man-made landforms. The above research contents should be performed from such aspects as formation and evolution of natural landforms, regional needs for socio-economic development, application of new materials, and innovation of engineering technical conditions. The spatial expansion and development process of man-made landforms are accompanied by the evolution of individual man-made landforms. Therefore, such relationships between the evolution and natural, humanistic, economic and political factors are worthy to be explored.

(4) Regional disparity of man-made landforms and their accumulative environmental effect

The greatest difference between anthropogenic geomorphology and traditional geomorphology lies in that, in addition to the natural internal and external forces, the former takes human activities as the third geomorphologic agent (Mu and Gao, 1990). Research on the regional disparity of man-made landforms should consider the influence of various natural geographical conditions on man-made landform construction. At the same time, the effect of diversified modes of human activities should also be taken into account. Many problems regarding man-made landforms are all related to human activities, but the human history is very short compared with the geomorphic development period. Hence, in the studies on anthropogenic geomorphology, the influence of the direction, speed, scale and fluctuation of different regional energy flow and material flow on the development of existing landforms should be paid attention to. Research on the environmental effect of man-made landforms should focus on the environmental effects of both anthropogenic geomorphological process and the past construction of man-made landforms. In addition, the regional disparity and accumulative effects at different spatial and temporal scales should be analyzed (Kondolf and Podolak, 2014). All of these will help us reduce the negative influence of man-made landforms on natural geomorphological environment.

(5) Environmental management on man-made landform and the international comparative study

With continuing research on anthropogenic geomorphology, people's understanding of man-made landforms and their environmental influences is gradually deepened. How to perform environmental management on man-made landforms in a scientific and effective manner will be a new study field of anthropogenic geomorphological research (Ma, 2008). The environmental management of man-made landforms should consider the occupation and

transformation of natural landforms by human socio-economic constructions and urban and rural planning, analyze the vulnerability of the environmental system of man-made landforms, and put forward corresponding management strategies. Affected by the differences in population and resource pressure, there may be huge differences in environmental management on man-made landforms in different countries. Drawing on the advanced experience of foreign countries in man-made landform constructions is conducive to the development of relevant theories and management policies of man-made landform research conforming to China's national situation. The newly proposed theories and management policies will facilitate the sustainable exploitation and utilization of geomorphological resources.

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