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# Analysis of socio-economic spatial structure of urban agglomeration in China based on spatial gradient and clustering

**JEL Classification:** *F43; F29; R14; R41; R58*

**Keywords:** *economic and social development; urban agglomeration; Central Plains Urban Agglomeration (CPUA); clustering; spatial gradient*

**Abstract**

**Research background:** Previous studies on the economic and social development of urban agglomerations mostly focus on a single primacy comparative analysis and efficiency evaluation. Spatial structure differentiation is an important feature of urban agglomeration. The lack of economic and social analysis on the spatial structure makes it impossible to determine the development positioning of each city in the urban agglomeration, which affects the sustainable economic devel-opment ability of these areas.
**Purpose of the article:** The objective of the article is to analyze the spatial development law and experience of urban agglomeration, this study explores the practice of economic and population spatial structure of city areas in China. For this purpose, CPUA and its central city Zhengzhou was taken as an example, the spatial gradient structure of example was analyzed.
**Methods:** Using economic and population data of 32 cities in this region, growth pole theory, and pole-axis theory, the economic and population spatial structure of urban agglomeration, the spatial gradient structure of central cities in urban agglomerations were analyzed with the method of cluster about radiation index.
**Findings & value added:** (1) In the process of the formation of CPUA, the geo-graphical spatial pattern plays a decisive role in economic and social development. This is an experience from developing countries. (2) CPUA presents a gradient development pattern with Zhengzhou as the center, and economic and social development gradually radiates to the metropolitan area, the core development area, and the character development demonstration area. (3) The economic and social gradients of Zhengzhou, the central city, present the hierarchy rules and characteristics which are driven by the Beijing-Guangzhou-Railway axis and the Longhai-Railway axis. (4) The central city of Zhengzhou still presents insufficient primacy in regional development, which shows that Zhengzhou accounts for 6% of the population of the Central Plains Economic Zone and 14% of GDP, and insufficient agglomeration. Different countries at different stages of economic development have different urban agglomeration development models. The conclusions from China provide new decision-making ideas and methods for spatial structure research and development strategy analysis of urban agglomerations.

## Introduction

In the process of economic and social urbanization, a city-regional system is formed by several densely distributed cities of different levels and the hinterland through spatial interaction in a specific regional space with a higher urbanization level, with regional network organization as the link. The emergence of urban agglomerations is a historical process of economic and social development. The city is the center of a city-regional system. Through the polarization effect, a large number of industries and populations were concentrated, and rapid development is achieved. With the expansion of the scale of the central city and enhancement of its strength, it has a radiation effect on the surrounding areas and formed a gradient structure circle in economic and social development. With the expansion of urban scale and improvement of intercity traffic conditions, especially appearance of expressways, the radiation areas of adjacent cities are getting closer and partly overlapped, and economic ties between cities are getting closer and closer, and mutual influence was becoming greater and greater, which could be considered as the formation of urban agglomerations (David *et al.*, 2013; Jankowiak, 2020; Kijek & Matras-Bolibok, 2019). The emergence of urban agglomerations is the product of the development of productive forces and gradual optimization of production factors in geographical space. Each urban agglomeration generally includes one or two central cities (except a few urban agglomerations which were multi-core) with relatively developed economy and strong driving function as the core, and consist of several neighbouring cities with close spatial distance, close economic and social ties, complementary functions, and orderly hierarchy. The development of urban agglomerations could promote the optimal allocation of resources in the region, and promote economic and social development of cities in urban agglomerations (Ames *et al.*, 2020). Through the circulation of central nodes, urban agglomerations could exchange needed goods, promote competition, and form space advantages (Ducruet & Beauguitte, 2014). Central cities also promote local economic development through financial, tax, and other economic means and personnel training (Pain *et al.*, 2012). Central cities must develop in advance, and at the same time, regional economic and social development and a certain urban system are required to form an urban agglomeration system with central cities as the core. Cities at all levels have specialized divisions and unique urban agglomeration systems. The central city is also the core and foundation for the formation of an open, multi-level, and network-based Economic Zone (Puga, 2010).

As an important regional unit for country to participate in global competition and international economic structure distribution, the urban agglomeration structure is directly related to the function of urban agglomeration and the improvement of national competitiveness (Guo & Lv, 2018). Reasonable structure of urban agglomerations requires the coordinated development of large-medium and small urban agglomerations and perfect pyramid proportion relationship among the hierarchical cities in urban agglomerations. The function of the central city could be spread to small and medium-sized cities through the network structure of urban agglomerations. China's urban agglomerations is unbalanced in size distribution and have great differences in spatial development, which hindered improvement of the comprehensive strength of urban agglomerations and the sustainable development of population, resources, and environment (Wang & Jin, 2018; Lu *et al.*, 2019a; Lu *et al.*, 2019b). Too much concentration or dispersal of the scale of cities and towns is not conducive to the effective utilization of regional resource allocation efficiency.

While scientifically identifying the scale and structure of urban agglomerations, and accurately judging the future economic and social development trends and existing problems of urban agglomerations, it is of great significance to enhance sustainable development and radiation of urban agglomerations (Alderson & Beckfield, 2004). As early as in the 20th century, distribution of urban systems has become an important research field of urban economics. European scholars put forward the concept and theory of urban scale distribution. The theory of urban primacy was based on summary of practical experience of urban system development, which was an important content of urban system development theory. It mainly studied the importance of the primary city and the rationality of urban system scale and measured the primacy by the proportion of regional economy and population of the central city. The two-city index, four-city index, and eleven-city index further supplemented the application of this theory. Besides, the Pareto distribution was used to approximate the city size distribution within a country. This method further expanded the vision of urban system research and put forward Zipf's Law with Pareto index approaching (Newman, 2005). Based on the exponential distribution of the urban system, "Fractal Theory" and fractal dimension theory, which integrated system thought and geometry, was used to study the distribution law of the urban system (Moratis & Egmond, 2018).

The research on urban scale structure in China start relatively late. Since the 1980s, the rank rule (Shi *et al.*, 2017a; 2017b), Pareto Law (Bianco & Casavola, 1999), fractal theory (Gu *et al.*, 2016; Liu & Chen, 2000), and other methods had been applied to the demonstration and analysis of urban scale structure in China and had achieved fruitful results. In the aspect of targeted research on the characteristics of urban scale structure in the urban agglomeration, relevant scholars mainly used many empirical analysis methods, such as Gibrat rule, primacy degree, regression slope, Gini index of urban scale distribution, to explain the basic characteristics and development law of urban scale distribution in urban agglomeration. Research on the urban scale structure of urban agglomerations mainly focuses on the Yangtze River Delta, the Pearl River Delta, the middle reaches of the Yangtze River, and other urban agglomerations (Lei *et al.*, 2020).

The above-related studies have laid a good theoretical and empirical foundation for this study, but most of the previous scholars used a single non-demographic or economic index to explore the hierarchical characteristics of urban agglomeration, which was difficult to accurately reflect the economic and social comprehensiveness of urban agglomeration. Previous studies on the scale structure system of urban agglomerations mostly separated qualitative structure from quantitative research and separated macrostructure analysis from micro quantitative analysis. Although the quantitative results of relevant studies on urban structure explained some of its characteristics, they couldn't provide a comprehensive understanding of the relationship between cities from the perspective of economic and social development. Based on the growth pole theory and point axis theory, this study explores the diagnosis and analysis of economic and social development from three levels of the centrality distribution and echelon structure of urban agglomeration and makes a quantitative evaluation of gradient structure by using gradient index model and cluster analysis (Cardoso *et al.*, 2019). Taking CPUA as an example, the scale structure system of large and medium-sized urban agglomeration was analysed, which are composed of 30 prefecture-level cities in Henan, Shanxi, Shandong, Anhui, and Hebei. This study systematically summarizes the economic and social structure of CPUA and the gradient of the central city, deduces the distribution law of urban scale structure of urban agglomeration, and puts forward targeted promotion countermeasures for the scale structure of CPUAs, to provide theoretical support and practical reference for the construction and development of China's urban agglomerations and the formulation of relevant plans.

## Literature review

In economic and social geography, the concept of spatial structure refers to an abstract or general description of the economic and social phenomenon distribution in the geographical space. Specifically, the urban spatial structure referred to the spatial concentration and distribution characteristics of population and employment within the city. The city's spatial structure was the result of spatial distribution with people's residence and economic activities, which was also the result of participants' preferences in economic activities and public policies for a long time. An important concept related to it was the agglomeration economy, which referred to the decrease in costs and the increase in output enjoyed by enterprises located in a certain area. When this effect continued in time, the agglomeration economy was dynamic (Burger *et al.*, 2015; Ji *et al.*, 2019). The spatial structure of a city was the result of agglomeration economies in different geographical spaces. Agglomeration led to the spatial concentration of enterprises and employment, and ultimately formed a single-center or multicenter spatial structure. The overall utility level of the city was negatively correlated with the number of centers (Capello & Camagni, 2000). Spatial structure of a city was the result of economic interaction between enterprises and households

(Krugman, 1991). Due to existence of agglomeration externalities, they tended to concentrate in a certain area (DelaHoz-Rosales *et al.*, 2019). The main center could obtain benefits of obvious agglomeration externalities, and at the same time, it could also make the surrounding non-central areas obtain certain benefits. From a spatial perspective, the outstanding feature of so-called urban areas or regionalized urban entities was that a series of geographically separated and functionally closely connected towns surround one or more large cities. Spatial structure presented by urban areas in the post-industrial era had a typical polycentric feature (Fang, 2013).

Scholars in the field of regional and urban economy paid attention to urban spatial structure initially from the point of view of the relationship between the scale and density, and economic efficiency of urban cities. Doubling the size of a city would increase productivity by 6 percentage points (Beaverstock *et al.*, 2000). The economic efficiency of cities with a population of more than 2 million was 8 percentage points higher than that of cities with a population of between 250000 and 2 million. Bart (2010) analyzed the relationship between city size and resource utilization efficiency using cross-sectional data from the manufacturing industry in the United States and Brazil, and concluded that externalities of economies of scale mainly originated from the localized economy rather than urbanized economy, and that cities engaged in specialized production, which showed a strong local economy. On the other hand, with the expansion of city scale, the local economy would disappear, which meant that resource utilization efficiency of the manufacturing industry in big cities was not necessarily higher (or even lower) than that in small cities. Boix and Trullen (2007) established two models, based on the localized economy and the diversity of intermediate input services, respectively, trying to reveal the relationship between labor employment density and productivity. Using employment data at the state level in the United States, the study found that if employment density doubled, labor productivity would increase by 6%.

At present, in the economic and social study of urban agglomeration structure and central city radiation gradient, theoretical models and methods proposed in the relevant literature were as follows.

One was the growth pole theory. Development of regional economy was unbalanced, and those with good location conditions would become the priority growth pole. The central city was the growth pole of urban agglomeration evolution, and the polarization effect and diffusion effect were the theoretical basis of agglomeration and radiation urban agglomeration planning (Jin *et al.*, 2015). The core view of growth pole theory was that economic development or economic growth was not evenly distributed in a certain area, but occurred around a specific pole. This pole often had a core industry, and related industries existed around the pole and developed through direct or indirect effects (Craig, 2018). The expansion of core industries meant an increase in output, employment, and related investment, along with the emergence of new technologies and new industrial sectors (Hu, 2015). Economic growth would not happen in every place. However, it first appeared at some points or growth poles, with different intensities. Economic growth would spread from the growth pole to the whole economy through a variety of channels, and formed a differentiated impact on different regional terminals. Growth pole of a region as a group of expansion industries located in urban areas, and economic activities within their sphere of influence was defined (Burger *et al.*, 2014).

The existence of these external economies tended to concentrate investors' investment behavior towards extreme growth. Therefore, the economic development of a country presented a dual structure. Economy of a country was divided into developed regions and developing regions. These researches pointed out that economic activity had obvious preferences in the spatial selection, and development of growth poles would have a certain impact on other regions of the country. Some of them are beneficial, while others are negative, namely trickle-down effects and polarization effects. Trickle-down effect would drop from the growth pole to economically backward regions, and its mechanism included interregional trade and capital transferred to the backward regions (Yin *et al.*, 2017). Besides, the growth pole was likely to attract part of labor force from backward areas, thus reducing population of backward areas (Chen, 2009). The polarization effect would hinder economic development of the hinterland in the following ways. It was difficult for industries in backward regions to compete with industries in growth pole regions, especially when the transportation infrastructure was complete. As the growth pole had better investment opportunities, investors in the hinterland would reduce their investment in the local area and shifted their investment activities to the growth pole. From the perspective of economic development in the hinterland, the polarization effect would cause it to lose excellent labor resources (Hatami & Firoozi, 2019). The growth pole absorbed key skilled workers, managers, and young entrepreneurs, which would make the hinterland human capital scarce (Erkoc, 2012).

The second was the point-axis theory. As a point of the growth pole, the central city formed a development axis with traffic and geographical connection between node cities. It mainly analyzed the agglomeration of points and formation of the axis, as well as radiation and guidance of the "point-axis" to regional economic development (Fang, 2019). In dot-axis development theory, the dot referred to the central city with a high population, employment scale and density, and a concentration of multiple social and economic functions, where the agglomeration economy could play a role (Hamme & Pion, 2012). The axis in the theory referred to the link that connected central cities of different scales. It could be called the development axis (Guijarro-Merelles & Lopez-Rodriguez, 2021). These axes were not subjectively imagined or artificially added, but they were composed of various traffic arteries, namely roads, railways, civil aviation, and water transportation. In addition, energy transmission trunk lines and communication trunk lines constituted an infrastructure link. This axis carried the flow of goods, personnel, production factors, information, knowledge, energy, and other material and non-material resources. With the increase of speed and scale of the flow of people, logistics, and information on the development axis, industry, employment, and population began to gather (Frenken *et al.*, 2007). Due to the imbalance of social and economic development in regional space, there was a "potential energy difference" of resource elements among the central cities. At this time, the axis played a role in reducing the difference between the centers, so that advantages of high potential energy centers continued to spread to low potential energy areas on the axis, and all kinds of material and non-material elements would act on the surrounding areas. By combining with production factors of surrounding areas, new productive forces could be formed to promote development of surrounding areas and finally achieve development trend of balanced spatial structure. Human social and economic activities did not occur and exist simultaneously in geographic space. It was a process from point to axis and from axis to plane. The final stage of development of social-economic activities in geographical scope was the integration of points, axes, and planes in space. In the early stage of economic development, its spatial structure was simple, and its economic activities were highly concentrated in a city center. The centripetal force played a leading role, and various element resources continued to gather to the center (Shi *et al.*, 2017). When the growth of the center reached a certain scale, the effect of centrifugal force began to appear, and at the same time, an axis was formed between the center and other surrounding sub-centers, and the center began to develop diffusely along development axis to the sub-center (Fang, 2018). The secondary centers on these axes would undergo a similar economic development process as the centers, from agglomeration to diffusion, and radiated around them to form new secondary centers, which were not necessarily located on the existing development axis, thus forming a new axis (Sauro, *et al.*, 2017). Activities spread to a larger scale. Point-axis development theory was a spatial linear advancement method in the process of economic development. It was a perfect combination of the breakthrough of growth pole theory and the linear advancement of gradient transfer theory.

At present, more researches focused on the comparative analysis of different central cities, from which the advantages and disadvantages, and development strategies of each central city were discussed. There were relatively few specific analyses of the structure of the Central Plain Urban Agglomeration and influence factors (Fernandez-Temprano & Tejerina-Gaite, 2020). Based on the study of urban gradient structure and radial development axis, it was of great significance to study the urban structure and gradient of Central Plain Urban Agglomeration and the Central Plains Economic Region, as well as the evolutionary development.

## Research methodology

### *Research scope and data sources*

Scientific development of the Central Plain Urban Agglomeration under the guidance of Zhengzhou National Central City is an important part of the high-quality development of the Yellow River Basin. The Yellow River Basin is the birthplace of China. The Central Plains Economic Region covers Henan Province and parts of Shanxi Province, Shandong Province, Anhui Province, and Hebei Province, covering 30 prefecture-level cities in 5 provinces, with a total area of about 290,000 square kilometers. In 2018, the total population of the country was 165,297,800, with a GDP of 898.188 billion EUR. The Central Plains Economic Region is a key development zone in the planning of main functional areas in China, with Zhengzhou metropolitan area as the core and the CPUA as the support. This zone plays an important strategic role in China’s overall development because of its important geographical location, developed transportation, huge market potential, and profound cultural heritage. It is an important strategic node for the development of the central plain area and a strategic development hub for China's industrialization and modernization. Zhengzhou is the capital of Henan Province, a megacity, the core city of CPUA, an important central city in Central China, and an important comprehensive transportation hub in China. In 2019, Zhengzhou has jurisdiction over six districts, one county, and five county-level cities. It has the total area of 7446 square kilometers, a permanent resident population of 10.352 million, an urban population of 7.721 million, an urbanization rate of 74.6%, and a GDP of 151.709 billion EUR.

To explore the central city economic and social radiation gradient of the urban agglomeration structure, it is necessary to select and establish an urban agglomeration development indicator system. A scientific and reasonable indicator system, on the one hand, was the basis and guarantee for reflecting the structure of urban agglomeration and it was also an important means to correctly guide the development of urban agglomerations (Cheng *et al*., 2011), on the other hand, it was the basis and key link for the scientific evaluation of coordinated development of urban agglomerations (Chen & Sun, 2012). To establish a scientific, reasonable, and feasible index system for the coordinated development of the urban agglomeration economy, there must be a clear and definite construction principle, then as a guidance, the hierarchical structure of the framework should be clear and reasonable and specific index content of its index system should covers all aspects, which are directly related to the quality of evaluation. After that, the evaluation index system of coordinated development of urban agglomeration can be established by selecting an appropriate construction method, according to the research aims. Among related bodies of research, since there are differences in understanding of the representations of coordinated development of urban agglomerations and the limitations of statistical data, the selection scope of index are different, therefore, the evaluation indicators used by the researchers are not the same. This paper synthesized the indexes of relevant literature and formed its own evaluation equation.

*Definition of gradient structure of radiation circle in the central city*

The radiation ability of a central city refers to the ability of the central city to influence surrounding cities and regions, which mainly depends on comprehensive influence procedures of the city's economic and social development level in the region. Early studies mostly measured radiation ability of cities from a single economic function, lacking embodiment of urban social function. This study introduces a population index to comprehensively evaluate radiation ability of the central cities. Radiation gradient of the central city is negatively correlated with distance and is related to transportation and administrative area, as well as the radiation receiving capacity of surrounding cities (Wang & Qu, 2017). In the study of the structure of urban circles, relevant scholars have carried out relevant research. Based on relevant research results of the definition of an urban circle and radiation model of the central city, this study makes a quantitative analysis of gradient and structure of the central city radiation circle in CPUA.

Central cities need to have strong comprehensive strength, transportation location advantages, technology, and industrial agglomeration abilities and to be able to integrate regional resources, to form agglomeration and diffusion centers, and to realize effective connection between the central city and surrounding cities in the flow of people, logistics, capital, information, as well as industry and technology. According to relevant research and literature review (Ke *et al.*, 2017), central cities occupy leading position in population size and urbanization level. Based on the comparison of GDP scale and city primacy, Zhengzhou, the central city of the CPUA, has been studied and analyzed in many kinds of literature.

After the central city is determined, circle center distance is determined around it, which is the distance between other cities in urban agglomeration and the central city (Kos *et al.*, 2020). Referring to relevant literature at home and abroad, it adopts calculation of economic distance.

Firstly, spatial distance should be determined. This study adjusts calculation method of spatial distance, which is average of road distance and straight-line distance between cities. Economic distance is obtained by correcting the average traffic distance and the spatial distance according to distance correction coefficient. According to reality of the CPUA, it changes ship transportation index to high-speed rail. The revised economic distance calculation formula is shown as formula (1).

$$D_e = \alpha \times \beta \times D_d \tag{1}$$

In formula (1), $D_e$ represents economic distance, and $D_d$ represents spatial distance. $\alpha$ and $\beta$ represent correction weight coefficients. $\alpha$ is the first correction weight coefficient, which is also called traffic correction weight coefficient. The CPUA is an inland urban agglomeration, and main modes of transportation are land transportation and air transportation. Therefore, it adjusts the determination of existing literature coefficient. $\beta$ is the second correction coefficient, which is development level correction coefficient, set by ratio of urban per capita GDP. The specific values are shown in Table 1.

Based on space interaction theory and law of distance attenuation, this study adopts field strength and radiation effect exponential model, which is shown as formulas (2) and (3).

$$Y_{ic} = \frac{\sqrt{P_i \times G_i} \times \sqrt{P_c \times G_c}}{E_{ic}^2} \tag{2}$$

$$C_{ic} = \frac{\sqrt{P_c \times G_c}}{E_{ic}^2} \tag{3}$$

In the formula (2) and (3), $Y$ is the city radiation effect index. $E$ is the field strength in the central city. $P$ is the urban population. $G$ is the city's GDP. $i$ is the serial number of the surrounding city, and $C$ is the central city.

*Cluster analysis of the spatial structure*

K-means clustering analysis has advantages of simple principle, fast convergence, and better clustering effect (Sangamuang, 2019). By applying SPSS software, this study uses the K-means clustering method to cluster radiation effect index of the CPUA. The basic idea of this method is to divide all calculated radiation effect observations into $K$ classes so that observed values in each class are closer to the center of it than the center of others, The distance between classes is as far as possible. Specifically, it should select $K$ from all observations as the class center firstly. Secondly, it should calculate distance between each other observation and each class center respectively, to which class center is closest. Then, observation is divided into the set of the class center, forming $K$ class. Thirdly, it should recalculate the average value between observed values in each class as the new class center. Fourthly, it should re-divide each observation to the nearest class center. Fifthly, it should repeat step three and step four until the center of all classes does not change.

Distance metric commonly used in K-means clustering is the square of Euclidean distance, which is shown as formula (4).

$$d(x, y)^2 = \sum_{i=1}^{N} (x_i - y_i)^2 = \|x - y\|_2^2 \tag{4}$$

In the formula (4), $x_i$ and $y_i$ are N-dimensional values of different samples $x$ and $y$. $N$ is the characteristic number.

The elbow method is commonly used to determine the best clustering number $K$ of the data set. Measurement index of this method is the sum of squares of inter-clusters errors and $S_{SSE}$, which refers to the sum of squared distances from all observations to the center of the class after each clustering is completed, which is shown as formula (5).

$$S_{SSE} = \sum_{i=1}^{K} \sum_{p=C_i} \left| p - m_i \right|^2 \quad (5)$$

In the formula (5), $C_i$ is the ith class set. $P$ is observation point in $C_i$, and $m_i$ is the center of $C_i$. With the increase of $K$, data set partition becomes more refined $S_{SSE}$ becomes smaller gradually, and finally it tends to be stable. There is an inflection point, which is also known as the elbow point, in the change process of $K$-$S_{SSE}$ curve. When decline of $S_{SSE}$ suddenly slows down, $K$ is the best value at this time. When it is greater than this value, it cannot bring more returns of clustering degree.

## Results

With continuous development of China's economy, the trend of regional economic integration begins to appear. Economic ties between cities continue to strengthen, and the central cities begin to play a leading role in development of regional economy, which originates from economic radiation power of central cities. The central city of urban agglomeration is the center of the regional economy the link that establishes domestic and international economic ties, and also represents competitiveness of urban agglomeration and region. It is of great significance to carry out evaluation of radiation gradient of the central city and to study regional urban structure. If spatial structure of urban agglomerations is not reasonable, poor coordination between cities will seriously affect development of urban agglomerations. If radiation power of central cities is weak, it is not reasonable to determine radiation gradient structure of central cities to coordinate balance of urban development stage, which will restrict competitiveness of urban agglomerations.

### *Analysis of spatial hierarchy of the CPUA*

The CPUA is a concentrated area of urbanization development in Central China, including 30 prefecture-level cities in five provinces, covering an area of 287000 km$^2$, with Zhengzhou metropolitan area as the center, including 1 megalopolis, 12 metropolises, and 17 medium-sized cities. The structure of the population scale is shown in Table 2.

In 2018, the State Council of China issued a document to support construction of Zhengzhou as a national central city. Zhengzhou is the core city, which should play its leading and radiating role to build a central city cluster with multi-level functions of the National Central City, regional city, small and medium-sized city, and small town. It's shown in Table 3.

According to development plan of the CPUA, it is composed of Zhengzhou metropolitan area, core development area, and radiation area, as shown in *Table 3*. Zhengzhou metropolitan area includes five cities. Core development area includes 12 cities in Henan, Jincheng in Shanxi Province and Bozhou in Anhui Province, and four radiation development areas, namely Northcross-regional collaborative development demonstration area, East Industrial Transfer demonstration area, West transformation, and innovation development demonstration area, and south efficient ecological economy demonstration area. Growth area and open space of the CPUA are composed of 5 provinces and 30 cities.

*Calculation of radiation gradient structure of Zhengzhou Central City*

According to field strength and radiation effect index model, data is collected and calculation results are shown in Table 4.

According to radiation effect index, it makes a systematic cluster analysis of the CPUA. The results are as follows.

The first category includes Xuchang, Xinxiang, Kaifeng, Luoyang and Jiaozuo.

The second category includes Jincheng, Zhoukou, Anyang, Heze, Luohe, Shangqiu, Handan, Zhumadian, Hebi and Pingdingshan.

The third category includes Sanmenxia, Xingtai, Jiyuan, Suzhou, Xinyang, Nanyang, Yuncheng, Puyang and Liaocheng.

The fourth category includes Changzhi, Bozhou, Fuyang, Huaibei and Bengbu.

*Analysis of measurement results*

According to economic and social development axis planning, it analyses development of the four-axis circle echelon and that of the four-axis, which is shown in Table 5.

According to the econometric equation method, the total population of cities on Jing-Guang development axis is 50.11 million, with the GDP of 26.45 billion EUR, and development level is also obviously ahead. Total population of cities on the Long-Hai development axis is 41.2 million, with the GDP of 21.71 billion EUR, and development level is also relatively high. Total radiation index of Jing-Guang development axis and Long-Hai development axis is also obviously higher. Analyzed from radiation index, radiation index of Zheng-He-Tai development axis is relatively high.

Comprehensive analysis shows that development foundation of Jing-Guang development axis is good. Overall development level is high, and Long-Hai development axis also has a strong development level, and development of Zheng-Wang-Ji axis and Zheng-He-Tai axis is weak. Combined with the actual situation, the Beijing-Guangzhou development axis and Long-Hai development axis have convenient transportation facilities. The earliest national transportation lines, namely Long-Hai railway and Beijing-Guangzhou railway, national highway 107 and national highway 310, emerging transportation lines, Beijing-Hong Kong-Macao expressway and Lian-Huo highway, Beijing-Guangzhou high-speed railway, and Long-Hai high-speed railway, make the cities on these two axes develop rapidly. On development axis of Zheng-Wan-Ji and Zheng-He-Tai, although all cities have been connected with expressways and railways, their transportation convenience is not as good as that of Long-Hai axis and Jing-Guang axis. In addition, high-speed railways on axis of Zheng-Wan-Ji and Zheng-He-Tai are under planning and construction, but they have not been operated yet.

Basic data of urban scale structure and development level of the CPUA are shown in Table 6.

From the analysis of radiation gradient structure clustering and field strength, metropolitan areas and sub-central cities are the first categories of cities with strong radiation. Cities in the radiation intensity of core areas are concentrated in the second and the third category, and the cities' radiation intensity of radiation development area is relatively weak. In terms of urban function positioning, regional central cities are mostly concentrated in the second category of cities.

From the perspective of scale structure index of the CPUA, the area, population, total revenue and expenditure of public budget and GDP of Zhengzhou National Central City account for 3%, 6%, 14%, and 12% of the CPUA respectively. It reflects spatial agglomeration of population, outstanding financial capacity and high level of economic development. Zhengzhou City carries 6% of population with 3% of area, possesses 14% of the province's financial capacity, and creates GDP of 12%. Those of Luoyang sub-central cities account for 5%, 4%, 4%, and 6% of the CPUA, respectively. It reflects the general level of population spatial agglomeration, financial capacity, and economic development. Those of the metropolitan area, excluding Zhengzhou, account for 11%, 16%, 23%, and 24%, which reflects the strong spatial agglomeration of population, strong financial capacity, and high level of economic development in the metropolitan area. The metropolitan area carries 16% of population with 11% of area, possesses 23% of the province's financial capacity, and creates 24% of

GDP. Those of the core development area, excluding metropolitan area and Luoyang, account for 25%, 23%, 18%, and 21%, which reflects that the core development area is large, but the financial capacity and economic development are at average level of the whole province. Those of 16 cities in the radiation development zone account for 62%, 56%, 44% and 43%. The space area and population proportion of radiation development zone are relatively high, more than 50% of the whole region, but the financial capacity and economic scale are less than 50%, and the potential for economic development is relatively large.

Population density of Zhengzhou National Central City is 1361 people per km$^2$. Urbanization rate is 73%. Per capita GDP is 13,097 EUR. Spatial density of GDP is 17,828,802 EUR per km$^2$. Relevant indicators are ahead of other development areas, and far higher than average level of the CPUA, reflecting development achievements and high leading ability of the central city. Population density of sub-central city Luoyang is 453 people per km$^2$. Urbanization rate is 58%. Per capita GDP is 8,818 EUR. Spatial density of GDP is 3.99 million EUR per km$^2$. Due to relevant ecological development indicators, planning requirements, and more mountainous areas in Luoyang, Population density index is not high, but density and per capita level of GDP are far higher than the average level of the CPUA. Population density of the metropolitan area is 919 people per km$^2$. Urbanization rate is 60%. Per capita GDP is 9,119 EUR. Spatial density of GDP is 8.38 million EUR per km$^2$. Relevant indicators are more ahead of the average level of the CPUA, reflecting that the metropolitan area has a relatively strong ability to receive radiation and a high level of development around the central city. Population density of the core development area is 576 people per km$^2$. Urbanization rate is 49%. Per capita GDP is 5,562 EUR. Spatial density of GDP is 3.2 million EUR per km$^2$. Relevant indicators are lower than the average level of the CPUA, reflecting that the core development area needs to be led by the central city to improve the overall development level and capacity of entire region. The population density of radiation development area is 566 people per km$^2$. The urbanization rate is 48%. Per capita GDP is 4,627 EUR, and spatial density of GDP is 2.62 million EUR per km$^2$. Relevant indicators are lower than the average level of the CPUA. The area and total population are more than 50%. The development level of the radiation development area is low and growth space is large. Under leadership and radiation of central cities and metropolitan areas, it is crucial to improving the overall development level of the CPUA.

Analyzing from development indicators of population density and urbanization rate, overall performance of the CPUA is gradually decreasing from the center, metropolitan area, core area, and development zone. From the analysis of GDP development indicators, situation of successive declines is the same. Overall scale analysis shows that in the three district development strategies of the CPUA. Zhengzhou is the center, with big cities gathering and medium-sized cities scattering, urban density and population density are decreasing, GDP density and per capita GDP decreasing, and spatial scale and development level stepping up.

*Positioning analysis of urban function in the CPUA*

Zhengzhou is the key city for development of the CPUA. The action plan for Zhengzhou to build a national central city from 2017 to 2035 further defines six functional orientations of Zhengzhou, namely international comprehensive hub, international logistics center, national important economic growth center, national dynamic innovation and entrepreneurship center, national inland open door, and innovation center of Chinese historical civilization inheritance. Luoyang is the sub-central city of the CPUA.

Regional central cities take large cities as development nodes and lead development of 4 distinctive regions to improve urban ecology, to develop coordinated industrial service functions, scientifically to construct new urban areas, to improve urban functions, and to promote industrial technology upgrading and urban service modernization.

Among important node cities, urban positioning function of Zhoukou, Xinyang, and Zhumadian is to promote development of its agricultural industries which have a better foundation. Urban positioning functions of Heze of Shandong Province and Yuncheng of Shanxi Province are to develop modern manufacturing and service industries and to accelerate the industrialization of agriculture. Positioning function of Luohe and Jiyuan is to promote well-founded and distinctive industries, to accelerate industrial upgrading promoted by scientific and technological progress, and to plan international development of regional industrial manufacturing (in Table 7).

*Analysis of development strategy of "point-axis" structure driven by the central city*

The planning of the CPUA is a development pattern of "one core, four axes, and four districts". It is necessary to strengthen the core cities and to make full use of the "meter" development axis.

One core refers to the metropolitan area led by Zhengzhou. Its development strategy is to further improve functions of science and technology center, industrial center and financial center, to build a new ecological urban area that is livable and productive, and to play a leading role in industrial agglomeration and radiation.

Four-axis refers to main development axis based on meter-shaped comprehensive transportation network of the CPUA. Structural development strategy along Beijing-Guangzhou development axis is to take advantage of basic advantages of axis development belt, to carry economic radiation and diffusion of the central city, to promote gathering capacity of node cities, to complete modern industrial layout and development of emerging industries, and to form north-south axis urban industrial dense belt. These belts connect with Beijing-Tianjin-Hebei and middle reaches of the Yangtze River urban agglomeration. Structural development strategy along Long-Hai development axis is to give full play to advantages of land bridge transportation, to enhance role of Zhengzhou, Kaifeng, and Luoyang in construction of the Belt and Road Initiative, to promote international economic and social connectivity and development, to form a node city, to develop international logistics, to undertake international industrial division. It may jointly build industrial clusters such as modern industries and traditional industries, and form a strong advanced manufacturing and urban agglomeration belt. Structural development strategy of Jinan-Zhengzhou-Chongqing development axis is to rely on construction of Jinan-Zhengzhou-Wanzhou high-speed railway, and to form a new logistics channel and industrial development axis. It may give full play to the supporting role of node cities and small and medium-sized cities along the line of the CPUA, cultivate and develop traditional industries and special industries, and connect urban development belt of Chengdu-Chongqing urban agglomeration and Shandong Peninsula urban agglomeration. Structural development strategy of Taiyuan-Zhengzhou-Hefei development axis is to rely on traffic construction of the high-speed railway axis, and to layout cities along the line. It may expand capacity, improve quality, speed up completion of the modern industrial layout along the line, and form urban and industrial development belt connecting the Yangtze River Delta Urban Agglomeration and the central Shanxi Urban Agglomeration Four development districts promote inter-provincial unity and give full play to advantages of connection. It may do a good job in the interconnection of talents, science and technology, and education, break regional barriers, and form a new type of cross-regional cooperation and development zone.

## Discussion

An urban agglomeration is an economic circle composed of many cities which are closely linked with each other in economy, industrial division and cooperation, transportation and social life, urban planning, and infrastructure construction. Free flow of factors between cities, efficient allocation of resources, docking of infrastructure, supporting of industries, and equalization of public services, will give full play to scale effect, agglomeration effect, and synergy effect of urban agglomerations. Analysis of radial gradient structure and axial development of the central cities of the CPUA is shown as follows.

First, in a specific geographical area, urban agglomerations have a considerable number of cities of different nature, types, and scales, relying on certain natural environmental conditions, with one mega or two mega-cities as the core of regional economy. With the help of modern transportation tools and integrated transportation network, as well as highly developed information networks, it is taking place and developing internal connections between urban individuals, and forming a relatively complete collection together. During development of the CPUA, population density of Zhengzhou and its metropolitan area is 1,361 people per $km^2$ and 919 people per $km^2$, which is much higher than average of 628 people per $km^2$, forming a densely populated central city. Economically, per capita GDP of the central city and its metropolitan area is 1,322 EUR and 9,122 EUR, which is far higher than average level of 5,457 EUR per capita. Spatial density of GDP in the central city and its urban area is 17.83 million EUR per $km^2$ and 8.38 million EUR per $km^2$ respectively, which is much higher than average of 3.79 million EUR per $km^2$, forming economic intensive and developed area of central cities. The formation of Zhengzhou’s central city status is determined by its spatial location and transportation infrastructure construction. Zhengzhou is the economic and population center of the CPUA. Scientificity and rationality of this process in theory and practice were discussed (Partridge *et al.*, 2009; Camagni *et al.*, 2015), and polarization effect and agglomeration phenomenon of central cities was verified by analyzing the central cities of the CPUA, and the universality of growth pole theory in regional economic development was further verified.

Second, it is found that in the process of urban agglomeration economic and social development, spatial structure of urban agglomeration presents characteristics of point-axis distribution. It forms development axis of nine cities with Zhengzhou as the central city, along north-south Beijing-Guangzhou railway transportation line and East-West Long-Hai railway transportation line. This spatial structure is consistent with spatial structure of regional development urban agglomeration discussed and analyzed by Fang (2019), Frenken *et al.* (2007). Difference is to further enhance radiation effect of spatial axis. The CPUA has constructed development axis of five cities along Zhengzhou-Wanzhou-Jinan high-speed rail transit line and six cities along Zhengzhou-Hefei-Taiyuan high-speed rail transit line. With development of the economy, growth pole will spread to the surrounding areas. Exchange of production factors needs transportation lines, power supply lines, and water supply lines to spread production factors to the surrounding areas, to attract population and industry to gather along axis of the CPUA, and this produces new growth points.

Third, in terms of economic and social gradient structure, the CPUA forms a spatial echelon structure with Zhengzhou as the center, metropolitan area, core development area, and radiation development area as a hierarchical structure. It forms some regional node cities, which provides support for radiation and diffusion effect along with the central city, and further improves spatial structure efficiency of the urban agglomeration. Population density of the central city, urban district, core development area, and radiation development area of Zhengzhou in the CPUA is 1,361 people per $km^2$, 919 people per $km^2$, 576 people per $km^2$, and 566 people per $km^{2,}$ respectively. Per capita GDP is 13,097 EUR per person, 9,119 EUR per person, 5,562 EUR per person and 4,627 EUR per person respectively. Spatial economic density is 17.83 million EUR per $km^2$, 8.38 `million EUR per $km^2$, 32.02 million EUR per $km^2$ and 2.62million EUR per $km^2$ respectively. Spatial echelon structure is obvious, which further verifies urban agglomeration spatial structure with Zhengzhou as the core and radiates the CPUA. Fang (2018), Erkoc (2012) conducted a theoretical analysis on spatial echelon structure of urban agglomeration development radiation was conducted and it was verified by taking development of urban agglomeration at home and abroad as an example. It was concluded that the central city would show gradient weakening in radiation process. This is because in radiation process of the central city along axis, exchange of production factors, scale effect, and synergy effect would weaken due to the radiation distance, and form a radiation ladder degree structure.

## Conclusions

Using the data of economic and social development report of 30 cities in the CPUA of China in 2018, based on spatial differentiation theory of economic geography, the central cities and gradients from the aspects of economy and population were explored by considering factors of geographical space, transportation, and interprovincial administrative division. The following conclusions can be drawn:

(1) In the process of the economic and social formation of urban agglomeration pattern, the geographical spatial pattern plays a decisive role.

(2) In the process of economic and social development of the CPUA, Zhengzhou has an obvious position as a central city with good geographical advantages. It is the transportation hub of China's railway, highway, and aviation. Its economy and population are in a leading position of the CPUA in China.

(3) The CPUA has formed a point-axis economic and social development structure with Zhengzhou as the center and along the Beijing-Guangzhou railway and Long-Hai railway.

(4) On the echelon economic and social development structure of urban agglomeration in Zhongyuan, through spatial gradient and cluster analysis, echelon development structure of Zhengzhou metropolitan area, core development area, and radiation area are determined.

The main contribution of this study is to analyze economic and social echelon and spatial structure of the CPUA in China from perspective of economy and population. Through descriptive structure analysis, radiation index, and cluster analysis, urban echelon structure, urban spatial geographic location, and transportation hub are established. The economic and social spatial and geographical structure of transportation affects the pattern of urban agglomeration, development structure of the CPUA with Zhengzhou as the center and along transportation line is formed. Through analysis of radiation index, urban agglomeration structure of metropolitan area and core development area is identified. The findings provide a reference for analyzing development status of the CPUA and determining development direction of each city. This result will provide theoretical choice and experience reference for the development of urban agglomeration in developing countries.

Empirical results have demonstrated formation of point-axis structure of development of the CPUA, but development trend under the leadership of Zhengzhou needs to be further interpreted by adding human and political factors. Further improvement and supplement of research content around economic and social development of the CPUA should be added. Indicators and calculation results will be revised, and changes in the spatial echelon structure of the CPUA development will be tracked dynamically and continuously to provide results for related studies on the urban agglomeration.

The limitation of this study is that there is no further distinction between quality of urban economic development and quality of population, and the data need to be updated. Another is the fact that due to the different actual situation of economic and social development stages between countries and China, the experience of urban agglomeration construction may not be fully applicable to other countries.

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## Annex

**Table 1.** Economic Distance Correction Weight Coefficient

| **Commuting distance correction weight coefficient *α*** | | | | | | |
|---|---|---|---|---|---|---|
| Vehicle combination | Train | Highway | High-speed railway | Trains and highways | Trains and high-speed railways | Three transportations |
| Weight $\alpha$ | 1 | 1.2 | 1.5 | 0.8 | 1.1 | 0.5 |
| **Economic drop correction weight coefficient *β*** | | | | | | |
| Per capita GDP ratio | >70% | 45%~70% | | <45% | | |
| Weight $\beta$ | 0.8 | 1 | | 1.2 | | |

**Table 2.** Urban Scale Structure of CPUA

| City size | Quantity | Name list of cities |
|---|---|---|
| city with 5-10 million urban residents | 1 | Zhengzhou |
| city with 1-5 million urban residents | 12 | Luoyang, Nanyang, Shangqiu, Xinxiang, Kaifeng, Anyang, Pingdingshan, Jiaozuo, Xuchang, Handan, Beng,bu and Fuyang |
| city with 0.5-1 million urban residents | 17 | Luohe, Jiyuan, Zhoukou, Xinyang, Zhumadian, Hebi, Puyang, Sanmenxia, Changzhi, Jincheng, Yuncheng, Xingtai, Liaocheng, Heze, Huaibei, Suzhou, Bozhou |

**Table 3.** Urban Hierarchy of CPUA

| City level | Name list of cities |
|---|---|
| Zhengzhou metropolitan area | Zhengzhou, Kaifeng, Xinxiang, Jiaozu,o and Xuchang |
| Core development area | Zhengzhou, Kaifeng, Xinxiang, Jiaozuo, Xuchang, Luoyang, Pingdingshan, Luohe, Hebi, Shangqiu, Zhoukou, Jiyuan, Jincheng, and Bozhou |
| Northcross-regional collaborative development demonstration zone | Anyang, Puyang, Changzhi, Xingtai, Handan, Liaocheng, Heze |
| Eastern Industrial Transfer demonstration zone | Huaibei, Bengbu, Suzhou and Fuyang |
| The southern high-efficiency ecological economy demonstration zone | Zhumadian, Nanyang and Xinyang |
| Western transformation and innovation development demonstration zone | Sanmenxia, Yuncheng |

**Table 4.** Calculated Results of Field Strength and Radiation Effect Index of Central Cities

| | | Cities | Population (10000 people) | GDP (100 million EUR) | Space distance (km) | Vehicle Amendment right | Economic correction right | Economic distance (km) | field strength | Radiation index | Radiation index ranking |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Zhengzhou | | Zhengzhou | 1014 | 1328 | | | | | | | |
| Sub center | | Luoyang | 689 | 608 | 122 | 0.5 | 1.0 | 61 | 0.86 | 555 | 3 |
| Metropolitan Area | | Xuchang | 444 | 371 | 89 | 0.5 | 1.0 | 45 | 1.60 | 650 | 1 |
| | | Xinxiang | 579 | 331 | 79 | 0.5 | 1.2 | 47 | 1.44 | 630 | 2 |
| | | Kaifeng | 457 | 262 | 70 | 0.5 | 1.2 | 42 | 1.81 | 226 | 5 |
| | | Jiaozuo | 359 | 310 | 74 | 0.8 | 1.0 | 59 | 0.92 | 308 | 4 |
| Core area | Long-Hai axis | Shangqiu | 733 | 313 | 201 | 0.5 | 1.2 | 120 | 0.22 | 106 | 11 |
| | | Jiyuan | 73 | 84 | 117 | 0.8 | 0.8 | 75 | 0.57 | 45 | 18 |
| | | Bozhou | 524 | 167 | 251 | 0.8 | 1.2 | 241 | 0.06 | 16 | 26 |
| | Jing-Guang axis | Luohe | 267 | 162 | 146 | 0.5 | 1.0 | 73 | 0.60 | 125 | 10 |
| | | Hebi | 163 | 113 | 138 | 0.5 | 1.0 | 69 | 0.67 | 91 | 14 |
| | Zheng- Wan-Ji axis | Pingdingshan | 503 | 279 | 130 | 0.8 | 1.2 | 124 | 0.21 | 78 | 15 |
| | Zheng-He-Tai axis | Jincheng | 234 | 177 | 124 | 0.5 | 1.0 | 62 | 0.84 | 171 | 6 |
| | | Zhoukou | 868 | 352 | 175 | 0.5 | 1.2 | 105 | 0.29 | 160 | 7 |
| Radia tion zone | Long-Hai axis | Sanmenxia | 227 | 200 | 234 | 0.5 | 1.0 | 117 | 0.23 | 50 | 16 |
| | | Suzhou | 657 | 213 | 277 | 0.5 | 1.2 | 166 | 0.12 | 43 | 19 |
| | | Yuncheng | 536 | 198 | 272 | 0.5 | 1.2 | 163 | 0.12 | 39 | 22 |
| | | Huaibei | 225 | 127 | 324 | 0.5 | 1.2 | 194 | 0.08 | 14 | 28 |
| | Jing-Guang axis | Anyang | 518 | 313 | 180 | 0.5 | 1.0 | 90 | 0.40 | 160 | 8 |
| | | Handan | 953 | 452 | 238 | 0.5 | 1.2 | 143 | 0.16 | 103 | 12 |
| | | Zhumadian | 704 | 310 | 210 | 0.5 | 1.2 | 126 | 0.20 | 94 | 13 |
| | | Xingtai | 737 | 282 | 289 | 0.5 | 1.2 | 174 | 0.11 | 48 | 17 |
| | | Xinyang | 647 | 313 | 309 | 0.5 | 1.2 | 186 | 0.09 | 42 | 20 |
| | Zheng- Wan-Ji axis | HeZe | 877 | 403 | 192 | 0.5 | 1.2 | 115 | 0.24 | 144 | 9 |
| | | Nanyang | 1001 | 467 | 243 | 0.8 | 1.2 | 234 | 0.06 | 40 | 21 |
| | | Puyang | 361 | 217 | 193 | 0.8 | 1.0 | 154 | 0.13 | 38 | 23 |
| | | LiaoCheng | 640 | 409 | 321 | 0.8 | 1.0 | 257 | 0.05 | 25 | 24 |
| | Zheng-He-Tai axis | Changzhi | 346 | 215 | 236 | 0.8 | 1.0 | 189 | 0.09 | 25 | 25 |
| | | Fuyang | 1071 | 230 | 327 | 0.8 | 1.2 | 314 | 0.03 | 16 | 27 |
| | | Bengbu | 384 | 224 | 441 | 0.5 | 1.2 | 265 | 0.05 | 13 | 29 |

**Table 5.** Axial Development Analysis Table of CPUA

| Development axis | Development Zone | Cities | Population (10000 people) | GDP (100 million EUR) | Radiation index |
|---|---|---|---|---|---|
| Long-Hai axis | Metropolitan Area | Luoyang | 689 | 607 | 555 |
| | | Kaifeng | 457 | 262 | 226 |
| | Core area | Shangqiu | 733 | 313 | 106 |
| | | Jiyuan | 73 | 84 | 45 |
| | | Bozhou | 524 | 167 | 16 |
| | Radiation zone | Sanmenxia | 227 | 200 | 50 |
| | | Suzhou | 657 | 213 | 43 |
| | | Yuncheng | 536 | 198 | 39 |
| | | Huaibei | 225 | 127 | 14 |
| | Summation | | 4,120 | 2171 | |
| Zheng- Wan-ji axis | Metropolitan Area | | | | |
| | Core area | Pingdingshan | 503 | 279 | 78 |
| | Radiation zone | HeZe | 877 | 403 | 144 |
| | | Nanyang | 1,001 | 467 | 40 |
| | | Puyang | 361 | 217 | 38 |
| | | LiaoCheng | 640 | 409 | 25 |
| | Summation | | 3381 | 1774 | |
| Jing-Guang axis | Metropolitan Area | Xuchang | 444 | 370 | 650 |
| | | Xinxiang | 579 | 331 | 630 |
| | Core area | Luohe | 267 | 162 | 125 |
| | | Hebi | 163 | 113 | 91 |
| | Radiation zone | Anyang | 518 | 313 | 160 |
| | | Handan | 953 | 452 | 103 |
| | | Zhumadian | 704 | 310 | 94 |
| | | Xingtai | 737 | 282 | 48 |
| | | Xinyang | 647 | 313 | 42 |
| | Summation | | 5,011 | 2645 | |
| Zheng-He-tai axis | Metropolitan Area | Jiaozuo | 359 | 310 | 308 |
| | Core area | Jincheng | 234 | 177 | 171 |
| | | Zhoukou | 868 | 352 | 160 |
| | Radiation zone | Changzhi | 346 | 215 | 25 |
| | | Fuyang | 1,071 | 230 | 16 |
| | | Bengbu | 384 | 224 | 13 |
| | Summation | | 3261 | 1509 | |

**Table 6.** Basic Situation Table of Zoning Structure of CPUA in 2018

| **Development Zone** | **Number of cities (seat)** | **Regional size ($km^2$)** | **Total revenue and expenditure of public budget (100 million EUR )** | **Urban density (Seat / 10000 $km^2$)** | **Year-end total population (10000)** | **Population density (Person / $km^2$)** | **Urbanization rate (%)** | **GDP (100 million EUR )** | **Per capita GDP (10000 EUR / person)** | **Spatial density of GDP (10000 EUR / $km^2$)** |
|---|---|---|---|---|---|---|---|---|---|---|
| CPUA | 30 | 283,574 | 2,755 | 1.05 | 17,801 | 628 | 51.00 | 10,756 | 0.55 | 379 |
| central city | 1 | 7,446 | 382 | 1.34 | 1,014 | 1361 | 73.00 | 1,328 | 1.31 | 1,786 |
| Sub-centre city | 1 | 15,230 | 123 | 0.66 | 689 | 453 | 58.00 | 607 | 0.88 | 399 |
| Metropolitan Area | 4 | 31,028 | 641 | 1.68 | 2,852 | 919 | 60.00 | 2,601 | 0.91 | 838 |
| Core area | 8 | 70,369 | 508 | 1.11 | 4,052 | 576 | 49.00 | 2,254 | 0.56 | 320 |
| Radiation zone | 16 | 174,731 | 1,224 | 0.87 | 9,883 | 566 | 48.00 | 4,573 | 0.46 | 262 |

**Table 7.** Urban Function Orientation of CPUA

| City positioning | Name list of cities |
|---|---|
| National central city, central city of the CPUA | Zhengzhou |
| National regional central city and sub-central city of the CPUA | Luoyang |
| National regional central city | Nanyang, Anyang, Shangqiu, Changzhi, Handan, Bengbu, Fuyang |
| National important node city | Pingdingshan, Zhoukou, Xinyang, Zhumadian, Hebi, Puyang, Sanmenxia, Yuncheng, Jincheng, Xingtai, Liaocheng, Heze, Huaibei, Suzhou, Bozhou |