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Analysis of the Spatial Adaptability of Gross Ecosystem Production, Gross Domestic Production, and Population Density in Chinese Mainland

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Abstract: As China is currently in a critical period of transition to green development, a quantitative analysis of the coupled synergy between economic growth, population migration, and environmental protection performance can provide a rational reference for the formulation of macro-policies in relevant regions. Based on these objectives, this study built a matching analysis framework between gross domestic production (GDP) density (GD), population density (PD), and gross ecosystem production (GEP) density (ED) to analyze the spatial heterogeneity of these three indicators among 362 municipal units in different regions of the Chinese Mainland from 2000 to 2020 based on satellite remote sensing images and statistical data. The spatial adaptability between them was explored by employing a center-of-gravity model. The findings of this study show that: (1) the GD, PD, and ED on the Chinese Mainland exhibited varying degrees of spatial heterogeneity on both sides of the Hu Line during the investigation period, with the general feature of being higher in the southeastern region and lower in the northwestern region; (2) the centers of gravity of GD, PD, and ED were all located in Hubei Province during the investigation period. The centers of gravity of PD and GD shifted 79.39 km and 109.72 km to the southwest, respectively, whereas the center of gravity of ED, remained relatively stable during the investigation period; and (3) the center of gravity distances between PD–GD, ED–PD, and ED–GD in 2020 were 99.31 km, 247.52 km, and 346.27 km, respectively, and the percentages of highly matched units ranked among the 362 samples were 72.93%, 23.48%, and 25.69% for GD–PD, GD–ED, and ED–PD, respectively. This study concluded that a synergistic spatial pattern of the population, economic layout, and land use on the Chinese Mainland has not yet been formed. Therefore, this study suggests that future policies should be committed to promoting the northwest Chinese Mainland movement of the center of gravity of GD and PD, as well as the southeast movement of the ED center.

Keywords: GDP density; GEP density; population density; adaptability; Chinese Mainland

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1. Introduction

In ancient times, population concentration was primarily determined by natural geography [1]. As productivity progressed and society continued to develop, industrial economies attracted people to cities [2]. Population agglomeration can contribute to the scale effect of economic growth [3]; thus, humans are increasingly connected with economic systems. However, with frequent migration and high population density, urban issues such as public transport deficiencies and car dependency are beginning to emerge, and the pressure on urban public services is constantly increasing [4,5]. The population concentration and economic activities in some areas also have significant impacts on the environment at different scales, such as climate change. Environmental systems also act as constraints or drivers of economic activity, and climate change may even affect population distribution on a century scale [1]. Consequently, modeling the population, consumption, inequality, and the two-way coupling between humans and the planet has become a focus of the scientific community, with research on the interconnections between these different elements gaining popularity. Generally, on a long timescale, natural geographical and socioeconomic factors are the key factors affecting population density, and from the perspective of spatial scale, the effects of physical geographical factors and socioeconomic factors on population density on a global scale show diversity. In economically-developed European countries, scholars pay more attention to the impact of natural geographical factors such as terrain, precipitation, temperature, etc., on population density. For example, Hanberry analyzed the spatial relationship between population density and temperature zoning, and the results showed that population density increased with a decrease in monthly maximum temperature in the hypertropical zone [6], indicating that concentrated populations generally did not develop at high maximum monthly temperatures of $\geq$36 °C. In contrast, since the land area of most European countries is relatively small, scholars are more interested in analyzing the spatial relationship between population density and economic and social factors at the micro-scale. For example, Erhart et al. integrated grid data on population density and distance-to-seacoast into the analytical framework, using Sweden as an example. The results of their trend and geographical analysis showed that the total human toxicity potential in Sweden was smaller than previously estimated when using the North European USEtox landscape settings and sloped downwards over time [7]. Notably, in some developing countries with relatively large populations, several topics have been extensively studied empirically, and research findings have supported the decision-making of national government departments. These topics include the impact of population concentration or urban expansion on environmental indicators and economic systems [8,9], the response of environmental quality to population concentration and economic growth [10], the correlation between energy use and environmental pollution [11,12], and impact of population agglomeration on sustainable agriculture [13].

On a smaller spatial scale, such as in the Longitudinal Range-Gorge Region (LGRG), only one or two physical geographical factors may play a key role in the impact of population density. A survey showed that physiographic factors and traffic network density have a great influence on population density, while factors such as temperature and precipitation have little influence on population distribution [14]. Certainly, on a larger spatial scale, all-natural factors may affect the spatial pattern of population density; however, the degree and form of influence must be different. China is a developing country with a large territory and fast economic growth, but its population density distribution is extremely uneven. The Chinese population is mainly distributed on the southeast side of the Hu Line, which connects the northeast and southwest of the Chinese Mainland. The Hu Line is the demarcation line between China's humid and arid areas, which corresponds to a mean annual precipitation of 400 mm [15] and is a major boundary between population centers and different environments in China [16]. Over the past two decades, in response to growing pressures on the environment, emissions reduction, and economic development, several studies have addressed regional development differences on both sides of the Hu Line from a spatial economic perspective. Some scientific topics have received attention from the Chinese government and scholars, including spatial patterns of urbanization [17], regional links between uneven population distributions, and economic growth [18–20]. Population growth, industrialization, and urbanization around China have placed considerable pressure on ecosystems, leading to a growing inability of available ecosystem services to sustain this pressure, and the protection of natural ecosystems and enhancement of their ecosystem services has become an urgent challenge [21]. Therefore, China has elevated green transition development as a national strategy and is actively promoting the creation of an ecological civilization. In this context, vegetation and environmental protection on both sides of the Hu Line [22], sustainable agricultural expansion and ecosystem service trade-offs [23], and land-use patterns and their changes are receiving increasing attention [24,25].

Previous studies on regional development differences on both sides of the Hu Line mostly explored the spatiotemporal correlation between population density and economic growth [18–20] or the interaction between economic and environmental systems in a single study [21–25]. Hence, this study focused on the pairwise relationship between gross domestic production (GDP) density (GD), population density (PD), and gross ecosystem production (GEP) density (ED) to explore the spatial heterogeneity, pairwise matching, and regional contribution of population, economic, and environmental systems on both sides of the Hu Line. The aim was to provide scientific support to different local government departments in making macroeconomic decisions.

2. Data and Methods

2.1. Data

2.1.1. Data Sources

The land-use classification data, population, and GDP data used in this study were based on the 1 km raster map provided by the Resources and Environment Science and Data Center, and the boundary data of Chinese municipal units were overlaid using ArcGIS 10.3.1. Next, the PD, ED, and GD were extracted and calculated for the 362 basic evaluation units. Supplementary GDP and population data for some units in 2020 were obtained from the China City Statistical Yearbook, and data distortion corrections were performed for other years. Drawing on previous investigations [20], this study calculated *GEP* using Equation (1) and used it to derive the ED values of each unit during the investigation period.

$$GEP = EPS + ERS + ETS \tag{1}$$

where *GEP* is gross ecosystem production, *EPS* is the value of ecosystem provisioning services, and *ERS* is the value of ecosystem regulating services. More detailed evaluation indices and data descriptions are provided in references [26]. *ETS* is the value of ecosystem tourism services.

2.1.2. Study Subject

The sample period investigated in this study was from 2000 to 2020, of which five years were selected to represent four typical periods. Considering the complexity of administrative divisions in China (Figure 1) and the availability of data, this study used 362 prefecture-level cities (including four municipalities directly under the central government and 30 counties under the jurisdiction of provincial administrative regions such as Xinjiang and Hainan) on the Chinese Mainland (Hong Kong, Macao, Taiwan, and Sansha City in Hainan Province were not included) as the basic evaluation unit. The strategic positioning and development priorities of the four regions (eastern, central, western, and northeastern) on the Chinese Mainland varied during the investigation period. In addition, the development processes of different provincial administrative units in the same region also differed significantly during the investigation period. Hence, this study comprehensively analyzed the results from multiple perspectives of regional and provincial areas.

2.2. Methods

2.2.1. Connotation and Characterization of Adaptability

The concept of adaptability originated in population ecology to describe the adaptation and evolution of different biological populations in their natural environments. Currently, it has been extended to industrial ecology and economic and management sciences to characterize the coherence of different agents or relationships of mutual matching [27–29]. This study attempted to reveal the matching and coordination among GD, PD, and ED through an adaptability analysis to provide a reference for governmental decision-making. It was assumed that GDP growth, population migration, and environmental protection performance within a unit were at different development levels at different times or that the GD–PD, GD–ED, and PD–ED may demonstrate different levels of matching at the unit or regional scales because of different priorities and levels of economic and social development in different areas. Within a specific period, as the GD, PD, and ED of each unit underwent coordinated development, the three were assumed to match pairwise in space, that is, the centers of mass of GD–PD, GD–ED, and PD–ED would overlap.

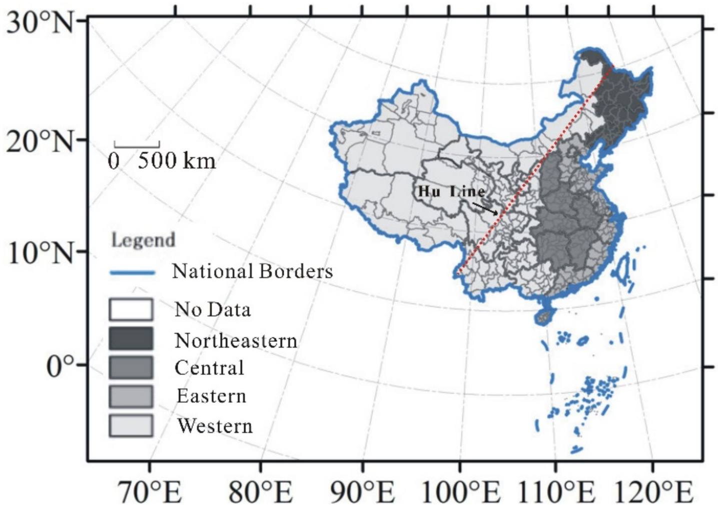

Figure 1. The administrative divisions in Chinese Mainland. Notes: Northeastern Chinese Mainland includes Heilongjiang, Jilin, and Liaoning Province; Eastern Chinese Mainland includes Hebei, Beijing, Tianjin, Shandong, Jiangsu, Shanghai, Zhejiang, Fujian, Guangdong, and Hainan Province; Central Chinese Mainland consists of Shanxi, Henan, Anhui, Hubei, Hunan, and Jiangxi Province; Western Chinese Mainland include Inner Mongolia, Gansu, Ningxia, Shaanxi, Xinjiang, Qinghai, Tibet, Sichuan, Chongqing, Guizhou, Yunnan, and Guangxi Province.

Based on these theoretical assumptions, the pairwise matching measures of GD, PD, and ED were determined, a statistical analysis of the original data was conducted, and the objective situation of economic and social development and environmental protection performance were elucidated during the investigation period, as shown in Table 1. First, the Delphi method was used to classify ED into four levels: low (<RMB 800,000/km^2), relatively low (RMB 0.8–1 million/km^2), relatively high (RMB 1–1.2 million/km^2), and high (>RMB 1.2 million/km^2); PD was classified into four levels: low (<333 persons/km^2), relatively low (333–666 persons/km^2), relatively high (666–999 people/km^2), and high (>999 people/km^2); and GD was divided into four grades: low (<10 million yuan/km^2), relatively low (10–50 million yuan/km^2), relatively high (50–10 million yuan/km^2), and high (>10 million yuan/km^2). Then, the matching was further divided into highly matched (grade difference = 0), intermediately matched (grade difference = 1), elementarily matched (grade difference = 2), and mismatched (grade difference = 3), according to the grade difference between each pair.

Table 1. Ranking criteria of matching and its connotation explanation.

Matching Levels	Distinguishing	Connotation Explanation
highly-matched	Grade difference = 0	No grade difference and extremely high adaptability between the two
intermediate-matched	Grade difference = 1	Small grade difference and high adaptability between the two
elementary-matched	Grade difference = 2	Medium grade difference and general adaptability between the two
mismatched	Grade difference = 3	Large grade difference and low adaptability between the two

2.2.2. Computational Model of Center of Gravity Trajectory

In the theory of economic geography or spatial economics, elements located at the regional spatial center of gravity maintain a relative balance of forces in all surrounding directions. As an evaluation index to measure the spatial distribution state of regional factors, time-series change in the regional spatial center of gravity can reflect the spatial evolution trajectory of regional development [19,30]. According to the previous definition of spatial matching and its related assumptions, if the barycenters of PD, GD, and ED completely coincide, it indicates that they are perfectly matched in space. Conversely, if the center-of-gravity distance between any two of the above three is larger, it indicates that the spatial matching between the two is lower.

Previous studies have measured the synergistic relationship or adaptability between ecosystems and economic systems using the coupling coordination degree model [20]. However, it must be noted that the coupling coordination degree model has some reliability issues [20]; and due to the lack of geospatial factors in the coupling coordination degree model, its description of adaptability lacks visibility. In this study, the center of gravity of the population, GDP, and GEP refers to the force point where the population size, economic level, or environmental protection performance, respectively, maintain spatial equilibrium. Based on the above understanding, to further analyze the spatial pattern of ecological welfare and the characteristics of its evolution from a spatial perspective, one may use a center-of-gravity model to measure the position of the center of gravity (longitude, latitude). The distance and direction of its movement for PD, GD, and ED in the target area within the observation period to improve the reliability of the test results through a spatial pattern evolution-aided analysis is as follows:

$$long = \frac{\sum_{k=1}^{31} I_k \cdot long_k}{\sum_{k=1}^{31} I_k}, lat = \frac{\sum_{k=1}^{31} I_k \cdot lat_k}{\sum_{k=1}^{31} I_k} \tag{2}$$

$$d_{t+1,t} = C \cdot \sqrt{(long_{t+1} - long_t)^2 + (lat_{t+1} - lat_t)^2} \tag{3}$$

$$D = (lat_{k+1} - lat_k)/(long_{k+1} - long_k) \tag{4}$$

In Equations (2)–(4): the $long_k$ ($long_{k+1}$) and lat_k (lat_{k+1}) are the longitude (*long*) and latitude (*lat*) of unit *k* (unit *k* + 1), respectively; I_k is the GD, PD, or ED of unit *k*; the d_{t+1} represents the movement of the index center of gravity between year *t* + 1 and year *t* (base year); the $long_t$ ($long_{t+1}$) and lat_t (lat_{t+1}) are the longitude and latitude of year *t* (year *t* + 1), respectively; *C* is the distance coefficient, representing the planar distance between longitude or latitude on the surface of the Earth (111 km is adopted in this paper); *D* is the coefficient of determination for the direction, where $D < 1$ indicates that the direction of movement of the center-of-gravity is within the range of (−45°, +45°) or (+135°, +180°) from the base year position; $D > 1$ indicates that the center-of-gravity is within the (+45°, +135°) or (−45°, 135°) range; $D = 1$ indicates that the direction of movement of the center-of-gravity is on the ±45° or ±135° diagonal; and $D = 0$ indicates that the center-of-gravity is moving in the 0°, ±90°, or ±180° directions.

3. Results

3.1. Spatial Distribution Characteristics of PD, ED, and GD

3.1.1. Population Density

Figure 2 shows that PD on the Chinese Mainland exhibited a significant and stable spatial divergence on both sides of the Hu Line. Except for several units in Urumqi, Hohhot, Lanzhou, Xining, and Yinchuan, where PD was >200 persons/km^2, the PD on the northwest side of the Hu Line was generally <100 persons/km^2 (Figure 2a–e), and the differences among units were relatively small. Conversely, except for several units in northern Heilongjiang, eastern Inner Mongolia, and southwestern Yunnan, the PD southeast of the Hu Line was mostly >200 persons/km^2. In addition, Figure 2 indicates that although the southeast side of the Hu Line had a higher PD, it still exhibited a cluster-dispersion characteristic: the PDs of Hebei, Shandong, Henan, and Jiangsu, which are located in the Haihe-Yellow-Huaihe Plain, were mostly >1000 people/km^2 (population agglomeration area), which was significantly higher than that of the neighboring areas. In addition, units with a PD of >2000 or <500 persons/km^2 coexist on this side, indicating that dispersion characteristics exist simultaneously. Finally, Figure 2e shows that the area covered by these population agglomerations decreased in 2020 compared to that in previous years, with a decrease in population density in Hebei, Henan, and northern Jiangsu. In addition, the PD of Zhejiang in southeast China has increased significantly.

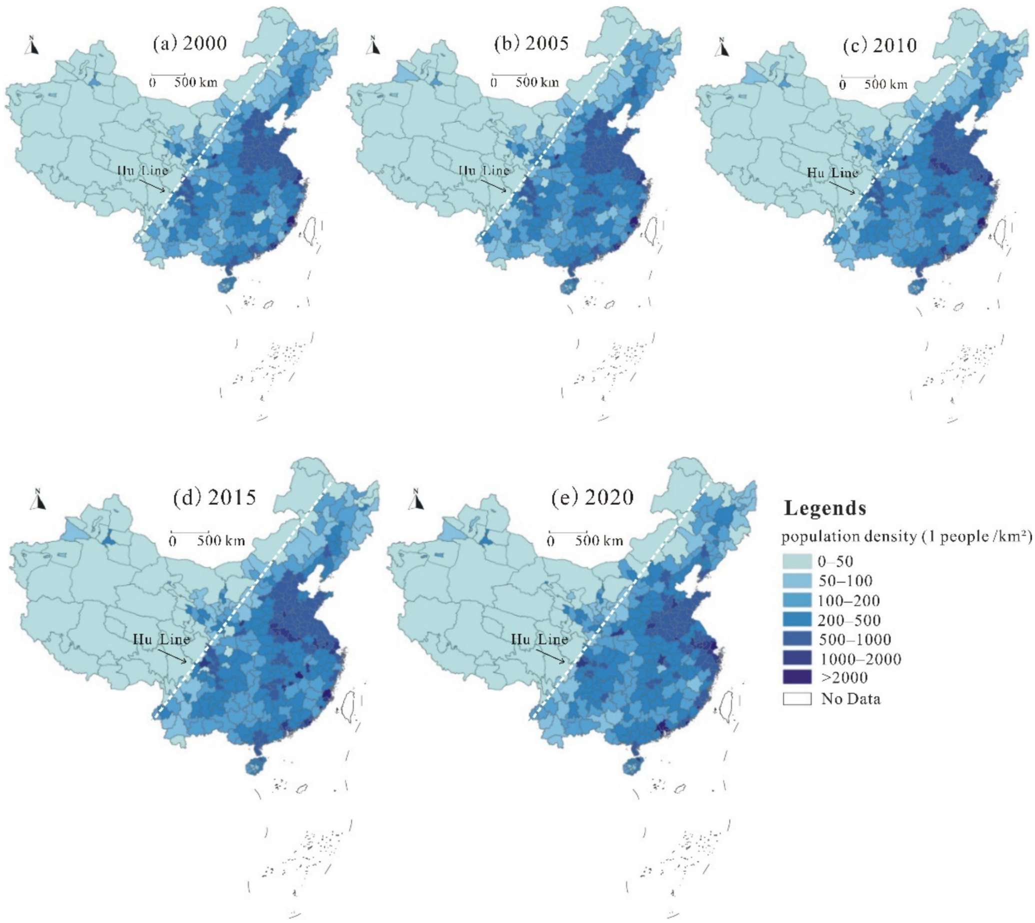

Figure 2. Spatial distribution characteristics of population density (PD) in Chinese Mainland during the investigation period.

3.1.2. GEP Density

Figure 3 presents the spatial distribution of the ED on both sides of the Hu Line on the Chinese Mainland during the investigation period. Significant spatial divergence was observed. The ED on the southeast side of the Hu Line was mostly >1 million yuan/km^2, especially in northeastern Heilongjiang, eastern Jilin, and eastern Liaoning in the northeast region and the southern Yangtze River basin and Hainan Island, whose EDs reached >1.5 million yuan/km^2. On the northwest side of the Hu Line, except for some areas, such as northeastern Inner Mongolia and northwestern Heilongjiang, the ED of most units was <1 million yuan/km^2, particularly in western Inner Mongolia, northern Gansu, and eastern Xinjiang, forming a continuous area of low ED values (<250,000 yuan/km^2). Finally, compared with the previous period, the ED of some units on the southeast side of the Hu Line decreased in both 2015 and 2020 (Figure 3d,e), and their overall comparative advantage over the other side at the beginning became less salient.

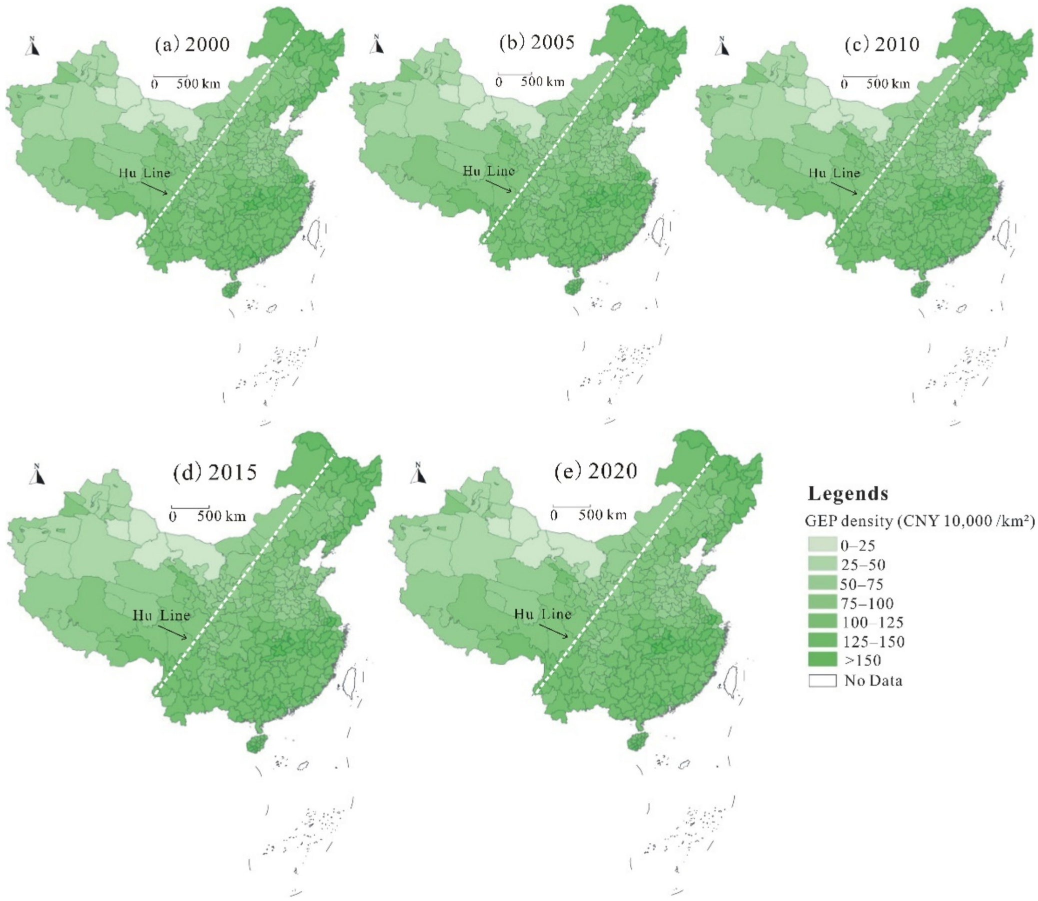

Figure 3. Spatial distribution characteristics of gross ecosystem production density (ED) in Chinese Mainland during the investigation period.

3.1.3. GDP Density

Figure 4 presents the spatial distribution characteristics of the GD on both sides of the Hu Line during the investigation period. Figure 4a–e show that it also featured a relatively significant spatial divergence of being higher in the southeastern region and lower in the northwestern region. This differed slightly from the previously addressed PD and ED because the phase characteristics of GD were more pronounced throughout the investigation period. In 2000 (Figure 4a), the GD of most units was >20 million RMB/km^2, except for Shanghai and Shenzhen. In 2005 (Figure 4b), the GD of some units in the eastern coastal region was >RMB 20 million/km^2, whereas, for most urban units, the GD remained at <RMB 20 million/km^2 during this period. In 2010 (Figure 4c), the GD of the developed regions, including Beijing, Tianjin, the Yangtze River Delta, and the Pearl River Delta, was >RMB 50 million/km^2, while a growing number of units had a GD of >RMB 20 million/km^2. In 2015 (Figure 4d) and 2020 (Figure 4e), the GD of most units in urban agglomerations, such as Beijing-Tianjin-Hebei, the Yangtze River Delta, and the Pearl River Delta, were >RMB 10 million/km^2. Concurrently, the GD of the surrounding areas, boosted by Zhengzhou, Wuhan, and Chongqing (with a GD of >RMB 10 million/km^2), increased significantly compared with those in previous periods, and the economic growth demonstrated an evolutionary trend of shifting toward the southwest.

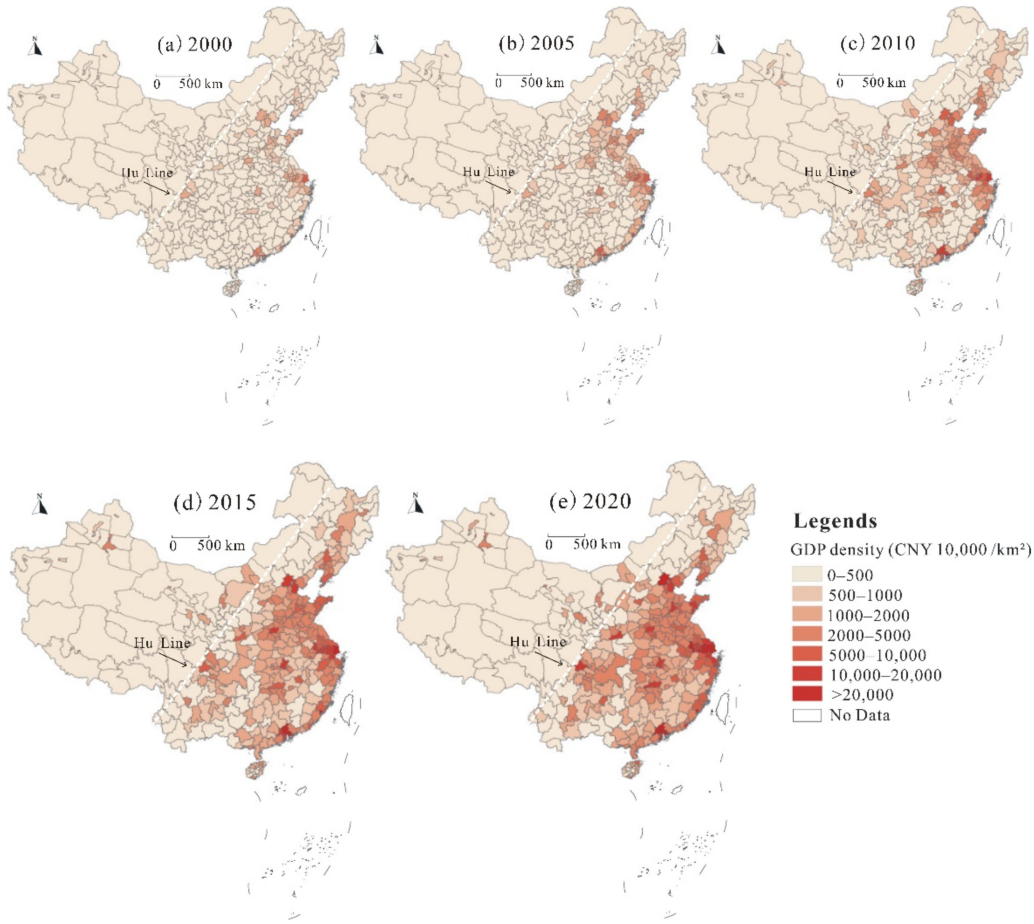

Figure 4. Spatial distribution characteristics of gross domestic production density (GD) in Chinese Mainland during the investigation period.

3.2. Spatial Adaptability between PD, ED, and GD

3.2.1. Location of the Center of Gravity and Its Moving Trajectory

Based on the combined regional- and national-scale perspectives of the eastern, central, northeastern, and western regions, Table 2 presents the center of gravity locations of population, GEP, and GDP densities. Regionally, the longitudinal or latitudinal changes in the three indicators were within 1° in all regions (except for the relatively small fluctuations in the center of gravity of GD in the western region in 2010 and 2015), which indicates that initially, they were all relatively stable. The centers of gravity of the three indicators for all five representative years were in Hubei Province in the central region, indicating that the PD, GD, and ED centers of gravity were on the southeastern side of the Hu Line. These results further indicate that they were relatively stable. Tables 2 and 3 also indicate the existence of minor differences among the three indicators: the center of gravity of PD was located between E 113°54′–E 114°15′ and N 30°47′–N 31°24′ (in Wuhan), and its center of gravity shifted 79.39 km toward the southwest; the center of gravity of the ED was located between 111°58′–E 111°59′ and N 31°55′–N 31°56′ (in Yichang), and its center of gravity shifted 79.39 km to the southwest. The center of gravity of GD was located between E 114°36′–E 115°10′ and N 30°13′–N 31°05′ (in Wuhan), and its center of gravity shifted 109.72 km to the southwest. Overall, the centers of gravity of both PD and GD moved toward the southwest; the speed (i.e., change in distance) of the latter was greater than that of the former, and the distance between them was 99.31 km in 2020. However, the center of gravity of GD did not follow them and shifted in the same direction, and as a result, the center of gravity distance between ED and PD, ED and GD are 247.52 km and 346.27 km, respectively, which is much higher than that between PD and GD.

Table 2. Location of center of gravity of population density, gross ecosystem production density and gross domestic production density in Chinese Mainland during the investigation period.

Region	Index	Position	2000	2005	2010	2015	2020
eastern	population density	Longitude	117°08′ E	117°00′ E	116°58′ E	116°56′ E	116°22′ E
		Latitude	29°55′ N	29°45′ N	29°41′ N	29°39′ N	28°49′ N
	GEP density	Longitude	115°37′ E	115°37′ E	115°37′ E	115°37′ E	115°37′ E
		Latitude	27°40′ N	27°41′ N	27°40′ N	27°40′ N	27°41′ N
	GDP density	Longitude	116°56′ E	116°53′ E	116°43′ E	116°41′ E	116°39′ E
		Latitude	29°19′ N	29°17′ N	29°10′ N	29°05′ N	28°39′ N
central	population density	Longitude	114°18′ E	114°19′ E	114°19′ E	114°22′ E	114°03′ E
		Latitude	31°05′ N	31°06′ N	31°07′ N	31°08′ N	31°56′ N
	GEP density	Longitude	113°42′ E	113°41′ E	113°41′ E	113°41′ E	113°41′ E
		Latitude	31°05′ N	31°06′ N	31°06′ N	31°06′ N	31°06′ N
	GDP density	Longitude	113°47′ E	113°49′ E	113°52′ E	113°55′ E	113°59′ E
		Latitude	31°51′ N	31°58′ N	31°56′ N	31°42′ N	31°45′ N
northeastern	population density	Longitude	124°08′ E	124°10′ E	124°10′ E	124°08′ E	123°51′ E
		Latitude	43°01′ N	43°03′ N	43°03′ N	43°01′ N	42°40′ N
	GEP density	Longitude	125°21′ E	125°20′ E	125°20′ E	125°20′ E	125°20′ E
		Latitude	44°33′ N	44°32′ N	44°32′ N	44°31′ N	44°31′ N
	GDP density	Longitude	123°46′ E	123°42′ E	123°41′ E	123°45′ E	123°36′ E
		Latitude	42°35′ N	42°42′ N	42°30′ N	42°33′ N	42°23′ N
western	population density	Longitude	103°40′ E	103°25′ E	103°23′ E	103°30′ E	103°08′ E
		Latitude	32°03′ N	32°04′ N	32°06′ N	31°57′ N	32°07′ N
	GEP density	Longitude	102°45′ E	102°46′ E	102°47′ E	102°50′ E	102°50′ E
		Latitude	32°06′ N	32°06′ N	32°05′ N	32°03′ N	32°04′ N
	GDP density	Longitude	101°42′ E	101°52′ E	102°49′ E	103°18′ E	102°24′ E
		Latitude	33°26′ N	33°44′ N	34°06′ N	33°02′ N	33°30′ N
Chinese Mainland	population density	Longitude	114°15′ E	114°06′ E	114°04′ E	114°05′ E	113°54′ E
		Latitude	31°24′ N	31°18′ N	31°17′ N	31°11′ N	30°47′ N
	GEP density	Longitude	111°59′ E	111°59′ E	111°58′ E	111°59 E′	111°59′ E
		Latitude	31°56′ N	31°56′ N	31°56′ N	31°55′ N	31°55′ N
	GDP density	Longitude	115°05′ E	115°10′ E	115°02′ E	114°55′ E	114°36′ E
		Latitude	31°05′ N	31°01′ N	30°58′ N	30°47′ N	30°13′ N

Table 3. Moving direction and distance of gravity center of population density, gross ecosystem production density, and gross domestic production density in Chinese Mainland during the investigation period.

Region	Index	PD	ED	GD
eastern	direction	southwest	southwest	southwest
	Distance (km)	148.84	1.53	79.61
northeastern	direction	southwest	southwest	southwest
	Distance (km)	50.18	3.62	37.42
central	direction	northwest	northwest	southeast
	Distance (km)	99.28	1.96	24.7
western	direction	northwest	southeast	northeastern
	Distance (km)	59.87	10.04	90.65
Chinese Mainland	direction	southwest	-	southwest
	Distance (km)	79.39	-	109.72

To further compare the trends in the center of gravity of different regions and their regional contributions, Table 3 presents the directions and distances of the PD, ED, and GD centers of gravity of different regions, which shifted 148.84 km, 1.53 km, and 79.61 km to the southwest, respectively. However, the PD, ED, and GD centers of gravity in the northeast region shifted 50.18 km, 3.62 km, and 37.42 km to the southwest, respectively. In addition, the PD and ED centers of gravity in the central region shifted 99.28 km and 1.96 km to the northwest, respectively, whereas that of the GD shifted 24.70 km in the opposite direction. The changes in the three indicators in the western region differed: the centers of gravity of the PD, ED, and GD shifted 59.87 km to the northwest, 10.04 km to the southeast, and 90.65 km to the northeast, respectively. In summary, all three indicators in the eastern and northeastern regions shifted southwest during the investigation period, which was consistent with the overall trend on the Chinese Mainland. In addition, a comparison of moving distances revealed that the regional contributions of PD and GD were greater in the eastern region and the regional contribution of the ED was greater in the northeast region.

3.2.2. Matching Comparison of Different Regions

Figure 5 presents the percentages of different matching levels between different pairs of indicators for the eastern, western, northeastern, and central regions for GD–ED, GD–PD, and ED–PD in the 2020 Figure 5a–c.

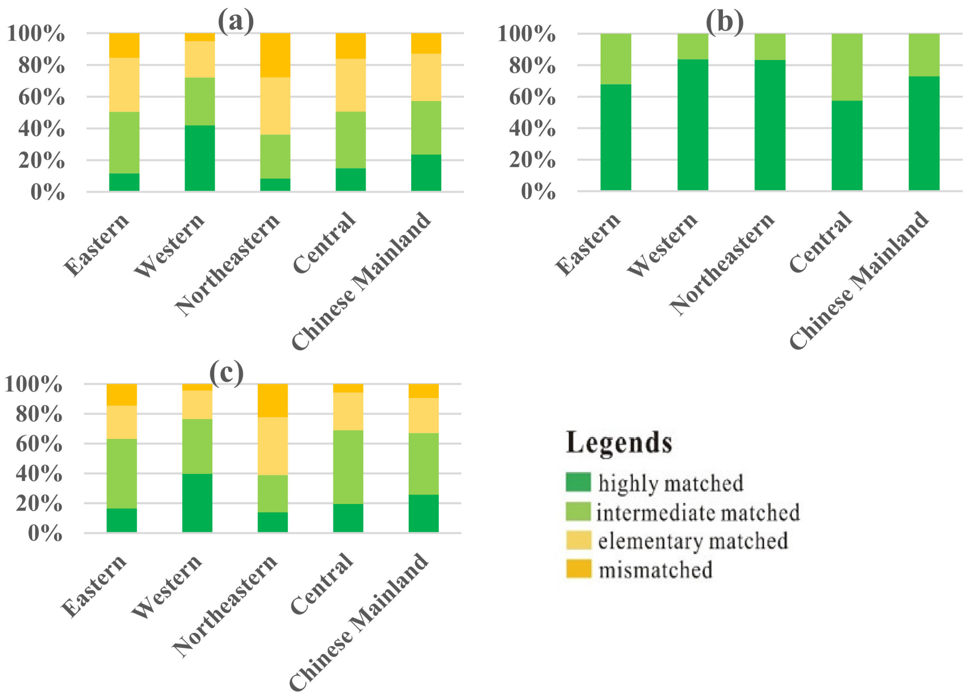

Figure 5. Proportion of units with different matching levels in (**a**) GD-ED, (**b**) PD-GD, and (**c**) ED-PD in Chinese Mainland during the investigation period.

Figure 5a shows that the proportion of GD–ED different matching grade units among all of the samples was highly matched (23.48%), intermediately matched (33.70%), elementarily matched (29.83%), and mismatched (12.98%). The western region had the highest percentage of highly matched units (41.91%) and the lowest percentage of mismatched units (5.15%); the northeastern region had the lowest percentage of highly matched units (8.33%) and a higher percentage of mismatched units (27.78%) than other regions. The difference between highly matched and mismatched (intermediately and elementarily matched) was >50% within each region: eastern (72.82%), central (68.97%), northeastern (63.89%), and western (52.94%).

Figure 5b shows that the matching of GD–PD was significantly different from that of GD–ED. In addition, the combined percentage of highly- and intermediately-matched units for GD–PD was 100% at the national level, with highly matched units accounting for 72.93% and intermediately-matched units accounting for 27.07%. The combined percentage of highly-matched units and intermediate-matched units for GD–PD in each region also reached 100%, and the percentage of highly matched units was >50% in each region: western (83.82%), northeastern (83.33%), eastern (67.96%), and central (57.47). In contrast, the percentages of intermediately matched units were: central (42.53%), eastern (32.04%), northeastern (16.67%), and western (16.18%).

Figure 5c indicates that the results of ED–PD are relatively similar to those of GD–ED. The proportion of units of different matching levels was: highly-matched (25.69%%), intermediately-matched (41.44%), elementarily-matched (23.48%), and mismatched (9.39%). Subtle differences also existed within different regions. Firstly, the percentage of units between highly matched and mismatched (intermediately and elementarily matched) was >50% within each region: central (74.71%), eastern (68.93%), northeastern (63.89%), and western (55.88%). Secondly, the northeastern region had the lowest percentage of highly-matched units (13.89%), while the percentage of mismatched units (22.22%) was higher than that of the other regions. Finally, in contrast to the northeastern region, the central region had the highest percentage of highly-matched units (49.43%), whereas the western region had the lowest percentage of mismatched units (4.41%).

4. Discussion

4.1. Comparison with Previous Studies

The findings of this study show that the PD on the Chinese Mainland exhibited a substantial spatial divergence on both sides of the Hu Line during the period investigated, with a general trend of being higher in the southeastern region and lower in the northwestern region, consistent with the overall trend of population migration on the Chinese Mainland [17]. Regarding the trajectory of the center of gravity, a previous study indicated that the centers of gravity of the PD in the eastern, central, western, and northeastern regions moved southwest, northeast, northwest, and southwest from 1978 to 2018, with average annual distances of 1.925, 0.380, 1.396, and 0.316 km, respectively [19]. Conversely, the findings of this study show that from 2000 to 2020, the centers of gravity of the PD in the eastern, central, western, and northeastern regions moved southwest, northwest, northwest, and southwest, respectively, with average annual distances of 7.442, 4.964, 2.996, and 2.509 km. From the comparison between this study and previous studies, regarding the average annual distance moved, the results are relatively higher in this study, indicating that the population migration rate on the Chinese Mainland has accelerated since 2000 compared with that of the previous years.

The findings of this study show that the GD on the Chinese Mainland exhibited a substantial spatial divergence on both sides of the Hu Line during the investigation period, generally trending from higher in the southeastern region to lower in the northwestern region, consistent with the overall trend of economic distribution [17]. Regarding the trajectory of the center of gravity, a previous study indicated that the centers of gravity of the GD in the eastern, central, western, and northeastern regions moved southwest, southeast, southeast, and southwest from 1978 to 2018, with average annual distances of 7.248, 2.075, 7.501, and 3.687 km, respectively [19]. Conversely, the findings of this study show that from 2000 to 2020, the centers of gravity of the GD in the eastern, central, western, and northeastern regions moved southwest, southeast, northeast, and southwest, respectively, with average annual distances of 3.981, 1.235, 4.533, and 1.871 km, respectively. In comparison to previous studies, the average annual distance moved was relatively lower in this study, indicating that the economic growth rate has decelerated since 2000 compared with that of the previous years.

The results of this study also indicate that the ED on the Chinese Mainland substantially diverged on both sides of the Hu Line during the investigation period, generally trending from higher in the southeastern region to lower in the northwestern region. The comparison between this study and previous studies is consistent with the overall trend of the gradient pattern of vegetation greening and land-use changes [15,24]. In addition, this study revealed that the trajectory of the center of gravity of the ED remained relatively stable from 2000 to 2020, which shows that clustered ecological land degradation coexisted with large-scale ecological restoration on the northwestern side, while multipoint farmland occupation and the distribution of the Grain for Green project caused most of the ecological land change on the southeastern side [25]. Although these results reflected the environmental protection performance on the Chinese Mainland under the constraints of the green development strategy, they also reflected the changes in the population migration and economic pattern. The slowdown of the economic speed in the northeast leads to population contraction; the strengthening of provincial capital strategy in the central and western regions promotes economic growth and population inflow, and the focus of GD and PD moves to the southwest, resulting in the low spatial matching between ED and PD, and between ED and GD.

4.2. Study Limitations

Whether a country's population density, land-use types, and economic distribution are synergistic and matched-agglomerated in space would significantly affect its coordinated regional development and socio-economic efficiency. Therefore, it is of theoretical and practical significance to explore multiple relationships between them. Notably, because of data limitations, the focus was only given to the twenty-year development process of elevating the "green development strategy" to the "ecological civilization strategy" on the Chinese Mainland for empirical analysis. As the data sources and evaluation indicators are not identical to those of previous research, the findings of this study are not entirely consistent with previous research findings. Hence, in the future, subsequent analyses should be conducted over a longer period using a richer index system. Furthermore, previous research findings also revealed that the impact of urbanization and urban migration on environmental protection performance is regionally heterogeneous and that the impact of economic and social factors [30], including energy intensity and industrialization level, cannot be ignored. These aspects were not addressed in this study, and more in-depth research is required in the future.

5. Conclusions and Policy Implications

The main conclusions of this study are as follows: (1) The GD, PD, and ED on the Chinese Mainland exhibited varying degrees of spatial heterogeneity on both sides of the Hu Line from 2000 to 2020, generally being higher in the southeastern region and lower in the northwestern region; (2) the centers of gravity of GD, PD, and ED on the Chinese Mainland were all located in Hubei Province from 2000 to 2020. The centers of gravity of PD and GD shifted 79.39 km and 109.72 km to the southwest, respectively. Due to the center of gravity of ED remaining relatively stable during the investigation period, its distance from the center of gravity of PD and GD gradually dwindled; (3) The center of gravity distances between PD and GD, ED and PD, and ED and GD were 99.31, 247.52, and 346.27 km in 2020, respectively, and the percentages of highly matched units ranked among the 362 samples were 72.93%, 23.48%, and 25.69% for GD–PD, GD–ED, and ED–PD, respectively; and (4) during the survey period, the population distribution had a high match with economic growth and maintained a similar trend of change; however, the pairwise matching between ecological spatial pattern and population distribution pattern and between economic growth pattern and ecological spatial pattern remained relatively low compared with that between economic growth pattern and population distribution pattern.

The policy implications of this study are as follows: (1) Although the ED on the southeast side of the Hu Line has been relatively high, it still does not match its own higher PD and GD. To improve the spatial matching between the three indicators, future policies should be committed to increasing investment in environmental protection and promoting ecosystem carrying capacity and the value of ecosystem services per unit area in the southeastern Chinese Mainland. While ensuring that the arable land area is not reduced, the effects of ecological restoration and environmental protection should be improved in the major food-producing regions in the northeast and east to facilitate the shift in the center of gravity of ED toward the southeast; (2) Although the ED on the northwest side of the Hu Line is relatively low, it does not match its own lower PD and GD. To improve the spatial matching between the three indicators while promoting the creation of ecological function areas, the shift in the centers of gravity of PD and GD toward the northwest should be promoted. Firstly, governmental subdivision needs to continue to promote the strategies of "opening up in western China", "revitalization of northeast China", and "rise sharply in central China" to promote economic growth on the Chinese Mainland in addition to the southeast coastal areas. While promoting economic growth, governmental subdivision needs to increase the level of infrastructure construction and social service security in these areas to reasonably guide industrial workers to migrate to northwest China to the northwest side of the Hu Line; and (3) In response to ecosystem degradation from rapid economic development, the Chinese Mainland should begin investing heavily in protecting and restoring natural capital starting in 2000. However, the findings of this study show that although national conservation policies contribute significantly to the increases in ecosystem services, the Chinese Mainland is yet to have population distribution patterns, economic growth patterns, and even land-use patterns; therefore, comprehensively considering the natural geographical conditions and ecosystem services supply and demand of the Chinese Mainland, the strategic orientation in its different regions should focus on different key points. In particular, scale-oriented conservation policies of ecological land should be replaced by cooperative conservation on an increasing scale and with optimized spatial patterns.

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