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Monitoring Spatial Patterns and Changes of Ecology, Production, and Living Land in Chinese Urban Agglomerations: 35 Years after Reform and Opening Up, Where, How and Why?

Shisong Cao [1,2], Deyong Hu [1,2,*], Wenji Zhao [1,2], You Mo [1,2] and Shanshan Chen [1,2]

[1] College of Resource Environment and Tourism, Capital Normal University, Beijing 100048, China; caoshisong@gmail.com (S.C.); zhwenji1215@163.com (W.Z.); sweetymoyou@163.com (Y.M.); amchenshanshan@163.com (S.C.)

[2] Key Laboratory of Resource Environment and GIS of Beijing, Beijing 100048, China

* Correspondence: deyonghu@cnu.edu.cn

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Abstract: Chinese urban agglomeration (UA) has gradually become a new world economic center and the strategic region of the "The Belt and Road Initiatives". The spatial patterns and variations of ecology–production–living land (EPL) profoundly affect UA's development and its ecological environment. Unfortunately, scientific understanding about the trajectories, patterns and drivers of EPL changes in Chinese urban agglomerations (UAs) since reform and opening up is still very limited. The aim of this paper was to monitor those characteristics during the last 35 years. Here, we proposed a new classification system of EPL, including ecology land (EL), industrial production land (IPL), agricultural production land (APL), urban living land (ULL) and rural living land (RLL) due to Chinese urban–rural dual structure. Then, we extracted EPL land from the Chinese LUCC product, which is the recently released remote sensing data product of high resolution spatial land use data in China at national level. Furthermore, we analyzed the spatial-temporal trajectories and driving factors of EPL for Chinese UAs during 1980–2015. The results showed that: (1) ULL and IPL in Chinese UAs were increased rapidly, while EL and APL were seriously decreased. (2) The growth patterns of ULL and IPL had shown a spatial heterogeneity. As to different regional UAs, the expansion rates of ULL and IPL ranked from high to low were as follows: eastern, central, western, and northeastern UAs. (3) National policies, population, and economy dominated the spatial-temporal changes of EPL in Chinese UAs. (4) The multi-planning integration in the structure of land use should be strengthened at UA-scale.

Keywords: urban agglomeration; ecology–production–living land; multi-planning integration; Chinese remotely-sensed LUCC product

1. Introduction

Over the past 35 years, urbanization and industrialization has become a global phenomenon [1,2]. Especially in China, the rates of urbanization and industrialization have been unprecedented and it has attracted global attention [3]. As a result, cities in China are no longer isolated but rapidly concentrated and linked together in form of urban agglomeration (UA) [4,5]. UA in China is generally characterized by coordinated development, industrial transfer, infrastructure sharing, and population concentration [6,7]. Specifically, Chinese central government has been promoting urban agglomerations (UAs) as the main spaces of the new type urbanization over the past decades. Now, with the transfer of the world economic center and the proposal of the "The Belt and Road

Initiatives", Chinese UA has gradually become a new geographical unit for participation in worldwide competition and cooperation [8].

A land use system consists of socio-economic and ecological subsystems, which generally conduct ecology, production, and living functions [9,10]. Multi-function in a land use system refers to functions that provide products and their services from different land use types [11], and also reflects the status and performance of a regional land use.

After reform and opening up in 1978, Chinese UAs have experienced rapid urbanization and industrialization. As a result, the accelerated expansion of urban and industrial sprawl has caused a number of environmental problems concentrated in UAs [12–16], such as ecological degradation [17–19], excessive land uses [20,21] and so on. Because of these problems, the report at the Fourth Session of the Twelfth National People's Congress in 2016 emphasized that the objectives of land use should focus on integrated development for production, living, and ecology in China [22]. In this context, exploring spatial-temporal changes and drivers of ecology–production–living land (EPL) over the past decades in Chinese UAs is very important for sustainable development and informed land use planning.

The spatial-temporal patterns and changes of EPL profoundly affect UA's development and its ecological environment. The scientific understanding about the trajectories, patterns and drivers of EPL in Chinese UAs since reform and opening up is still very limited for the following reasons:

(1) There were few reliable data to support the study of trajectories, patterns and drivers of EPL in Chinese UAs from 1980 to 2015. The unique national Chinese remotely-sensed LUCC product of 1980 and 2015 was just released by Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (RESDC) in 2017. Before this, the data can only cover the period of 1990–2010.
(2) Although the importance of promoting UAs as the main space for the new type urbanization is gradually recognized by government and academics, research on urban agglomeration is still limited due to their late development, which is less than 35 years in China. Its spatial delineation, basic connotations, construction foci, and degree of development are less certain and more contentious [8].
(3) The rapid development of economy and society made scholars pay more attention to the urbanization and industrialization but ignore integrated analysis of production, living, and ecology.

Based on above analysis, the objective of this study therefore is to comprehensively analyze the spatial-temporal trajectories and driving factors of EPL in Chinese UAs after reform and opening up. To achieve this goal, we first proposed a new classification system of EPL, including ecology land (EL), industrial production land (IPL), agricultural production land (APL), urban living land (ULL) and rural living land (RLL) due to Chinese urban–rural dual structure. Then, we performed additional validations for the new released Chinese remotely-sensed LUCC product of 1980 and 2010. Further, we extracted EPL in Chinese UAs from the LUCC product in 1980, 1990, 1995, 2000, 2005, 2010, and 2015. Finally, we analyzed the EPL spatial-temporal changes and its drivers during 1980–2015. The workflow of our study is illustrated in Figure 1.

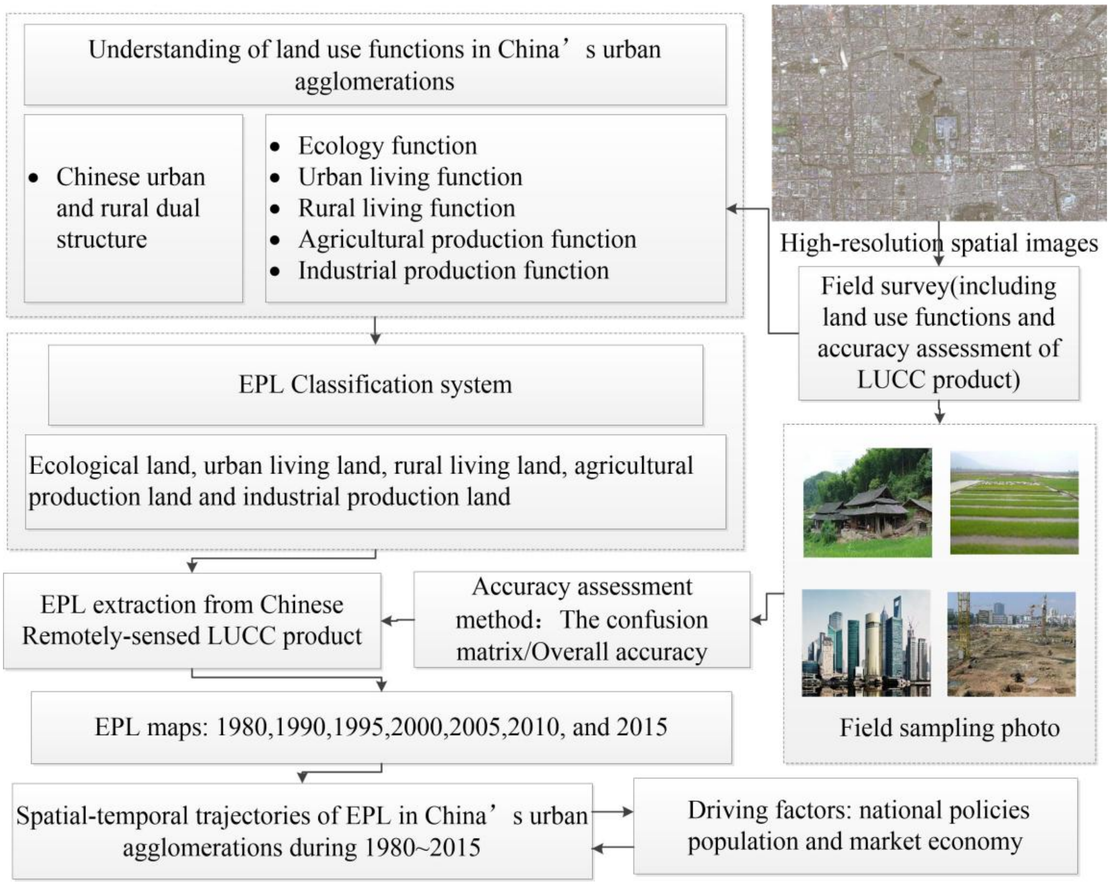

Figure 1. Workflow of our study Note: EPL represents ecology–production–living land.

2. Study Area and Data

2.1. Study Area

Because there are still some contention and controversy on the spatial delineation and quantity of Chinese UAs [23], we chose 10 major UAs that are agreed upon by most scholars as the study area: Beijing-Tianjin-Hebei UA (BTH), Yangtze River Delta UA (YRD), Pearl River Delta UA (PRD), Chengdu-Chongqing UA (CC), Middle Yangtze UA (MYT), Shandong peninsula UA (SDP), Western Taiwan Strait UA (WTS), Central and southern Liaoning UA (CSL), Central Plain UA (CP) and Guanzhong UA (GZ). The spatial delineation of these UAs are according to Fang et al. [8]. The study area is shown in Figure 2.

The 10 UAs are not entirely concentrated in the coastal zones of China. Five of them are distributed in the eastern zone, one in the northeastern zone, two in the central zone and the other two in the western zone. In 2010, the land areas, population and Gross Domestic Product (GDP) in these 10 UAs account for 10%, 39.44% and 67.68% of the national level, respectively. The 10 major UAs are the strongest land exploitation regions, and have the most development potential. They are important support for Chinese national economy and the engine of Chinese rapid socioeconomic development.

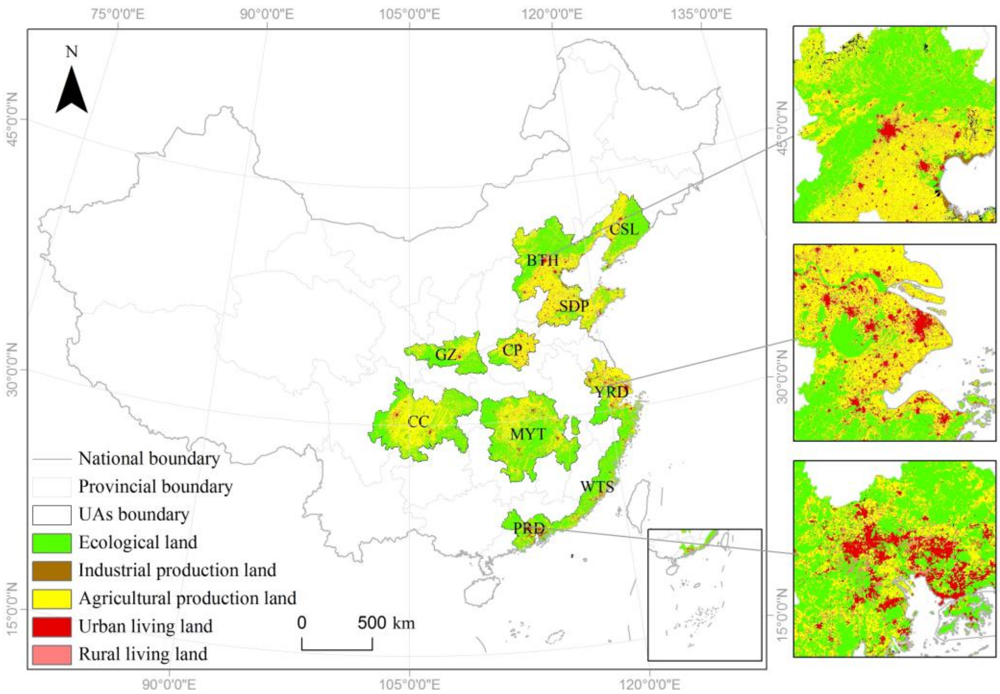

Figure 2. Overview of study area and spatial pattern of ecology–production–living land in 2015 Note: Abbreviations for Chinese 10 urban agglomerations (UAs): Yangtze River Delta (YRD), Pearl River Delta (PRD), Beijing-Tianjin-Hebei (BTH), Chengdu-Chongqing (CC), Middle Yangtze (MYT), Western Taiwan Straits (WTS), Shandong peninsula (SDP), Guanzhong (GZ), Central Plains (CP), Central and southern Liaoning (CSL).

2.2. Data Used

Chinese remotely-sensed LUCC product (1 km Components), with seven periods of 1980, 1990, 1995, 2000, 2005, 2010 and 2015, was provided by RESDC [24]. It was generated from two sources: (1) HJ-1A/1B data by CCRSDA, 2015; and (2) Landsat Thematic Mapper (TM)/ Enhanced Thematic Mapper (ETM+)/ Operational Land Imager (OLI). The classification system includes six classes and 25 subclasses (Tables 1 and 2). The LUCC product in 1980 and 2015 was just released by RESDC in 2017. Based on Chinese LUCC data, the EPL in 1980, 1990, 1995, 2000, 2005, 2010 and 2015 were extracted.

The accuracy assessment during 1980–2010 for Chinese remotely-sensed LUCC data was conducted in previous research [25,26]. In order to confirm the continuous and stable classification accuracy of EPL used in our study, our team members performed additional validations for 2015 LUCC product in seven UAs, BTH, YRD, PRD, CC, SDP, CSL, CP, and GZ, over Chinese spring festival holiday. The collected information of this field investigation included sampling point location, land use type, field sampling photo, the recoding of typical urban and rural landscape and high-resolution Google Earth images in 2015. In total, 7000 (1000 per urban agglomerations) sampling points were selected. There were 621 sampling points eliminated due to manmade error. The confusion matrix of Chinese remotely-sensed LUCC product in 2015 is shown in Table 1. The overall accuracy is 90.78%. We also performed additional validations for 1980 LUCC product by consulting Provincial Bureau of statistics of China and China Urban Statistical Yearbook. All area differences between product extracted and data from yearbook were within 5%. Based on above validations, we confirm that Chinese remotely-sensed LUCC data accuracy can meet with our research in this paper.

We also collected socioeconomic data from 1980 to 2015 as follows: GDP, primary industry GDP, secondary industry GDP, tertiary industry GDP, total population, non-agricultural population and agricultural population (Provincial Bureau of statistics of China and Chinese Urban Statistical Yearbook, 1981, 1991, 1996, 2001, 2006, 2011, and 2016).

Table 1. Confusion matrix of the Chinese remotely-sensed LUCC data in 2015.

Class	**Field Survey Truth Samples (Pixels)**								**Total Classified Pixels**	**Accuracy (%)**
classification	Cropland	Woodland	Grassland	Water area	Urban built-up area	Industrial land	Rural settlement	Other		
Cropland	930	22	24	2	6	2	26	8	1020	91.18
Woodland	9	443	12	3	4	2	14	3	490	90.41
Grassland	22	24	900	6	2	4	32	2	992	90.73
Water area	1	0	4	78	0	0	0	2	85	91.76
Urban built-up area	22	0	14	0	900	22	16	14	988	91.09
Industrial land	28	16	14	6	14	920	0	8	1006	91.45
Rural settlement	8	24	22	10	8	6	886	16	980	90.41
Other	20	21	6	11	4	14	10	750	836	89.71
Total sampling pixels	1040	550	996	116	938	970	984	803	6397	-
					Overall accuracy (%)					90.78

Table 2. Ecology–production–living land classification.

1st Level Classes	Subclasses	Description
Ecology land	Forestland	Land used for woodland, shrub land, forest land and so on
	Grassland	Land used for high coverage grassland, medium coverage grassland, and low coverage grassland
	Water area	Land used for river canal, lake, reservoir pond, beach, and so on
Production land	Agricultural production land	Land used for paddy land and arid land
	Industrial production land	Land used for factories, quarries, mining, and oil-field wastes outside cities as well as land for special uses, such as roads and airports
Living land	Urban living land	Land used for build-up area of large, medium and small cities and counties
	Rural living land	Land used for rural residential outside cities and counties
Others	Unused land	Unused land such as desert , saline-alkali land and so on

3. Methods

3.1. EPL Classification System

Figure 3 presents relationship and conflicts among five fundamental lands in Chinese UAs land use system. As can be seen in Figure 3:

(1) Field sampling photos exhibit the enormous differences between Chinese rural and urban regions. It is rather clear due to the dual structure of Chinese urban and rural regions. It was also certificated by our team members through our field investigation. Thus, we should consider these enormous differences in our EPL classification system.
(2) The ecology land (EL) has ecology functions, which is the support in a land use system. The production land has production functions, which is the land use system's guarantee. The living land has living functions, which is the land use system's ultimate purpose. Thus, they collaborate with each other and are indispensable.
(3) Due to the differences between Chinese urban and rural regions, the production land can be further divided into APL and IPL. The living land can be further divided into ULL and RLL. There were also conflicts among EPL in Chinese UAs land use system, for example, the conflicts between economic development and environment protection, as well as cultivated land reclamation and ecological production.

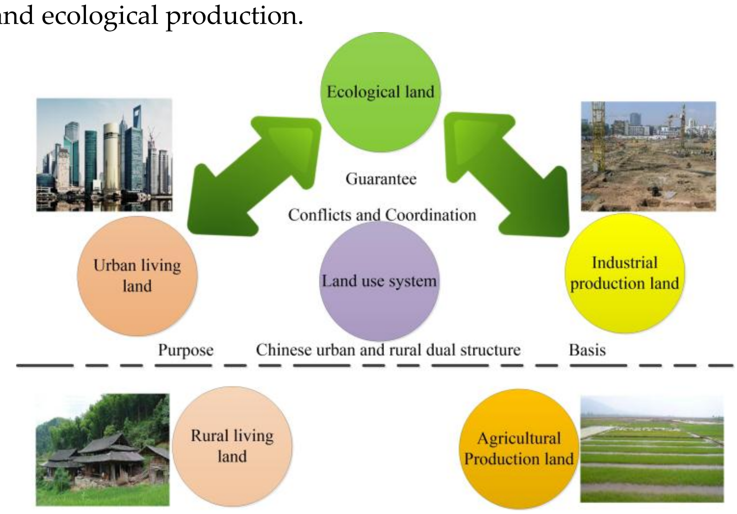

Figure 3. Relationship and conflicts among five fundamental lands in Chinese land use system. Note: Field sampling photos exhibit the enormous differences between Chinese rural and urban regions.

Based on above analysis, we divided land into five classes as follows (Table 2):

(1) EL: A region that can provide important ecological functions, such as climate regulation, water conservation and so on, including forest land, grassland and waters.
(2) IPL: A region can provide industrial products, including factories, quarries, mining, and oil-field wastes outside cities as well as land for special uses, such as roads and airports.
(3) APL: A region can provide agricultural products and their services, including paddy land and arid land.
(4) ULL: A region can provide functions of non-agricultural population living and public activities, including built-up area of large, medium and small cities and counties.
(5) RLL: A region can provide functions of agricultural population living and public activities, including rural residential outside cities and counties.

According to the above classification system, we map the spatial pattern of EPL in Chinese UAs from 1980 to 2015. Figure 2 exhibits spatial pattern of EPL in 2015.

3.2. Analysis Average Variation Rate and Driving Factors of EPL Changes

The average variation rate of EPL can be calculated by

$$VR = \frac{S_{t_1} - S_{t_2}}{t_2 - t_1} \quad (1)$$

where *VR* is the average variation rate between t_1 and t_2, S_{t_1} is EPL area (km^2) in year t_1, and S_{t_2} is EPL area (km^2) in year t_2.

In order to explore the drivers of spatial-temporal changes of EPL in Chinese UAs, we analyzed the relationship between EPL changes and the national policies. The national polices included reform and opening up in 1978, joining World Trade Organization (WTO) in 2001, all regional development policies and promoting UAs as the main spaces for the new type urbanization after 2006. Furthermore, we also analyzed the relationship between EPL changes and socioeconomic indices.

3.3.The Level of Urban Agglomeration and Regional Division

We divided 10 UAs into national level UAs and regional UAs (Table 3) for the analysis in this paper. The national level UAs included BTH, YRD, and PRD. The regional level UAs included CC, MYT, SDP, WTS, CSL, CP and GZ.

In order to explore the drivers of EPL spatial-temporal changes in this research, we divided the UAs into eastern, central, western and northeastern parts. The eastern UAs include BTH, SDP, YRD, WTS and PRT. The central UAs include CP and MYT. The western UAs include GZ and CC. The northeastern UA includes CSL (Table 3).

Table 3. The level of urban agglomerations and its regional division.

Classes Division	**Urban Agglomerations**
National level	Beijing-Tianjin-Hebei, Yangtze River Delta, Pearl River Delta
Region level	Chengdu-Chongqing, Middle Yangtze, Shandong peninsula, Western Taiwan Strait, Central and southern Liaoning, Central Plain, Guanzhong
Regional Division	Urban Agglomerations
Eastern coastal zones in China	Beijing-Tianjin-Hebei, Shandong peninsula, Yangtze River Delta, Pearl River Delta, Western Taiwan Strait
Central zones in China	Central Plain, Middle Yangtze
Western zones in China	Guanzhong, Chengdu-Chongqing
Northeastern zones in China	Central and southern Liaoning

4. Results

4.1. EPL Area Changes

4.1.1. EPL Changes in Different Classes Level

According to the above EPL classification system, the EPL variations and its variation rates in Chinese UAs from 1980 to 2015 were obtained, as can be seen in Figure 4 and Table 4.

(1) During 1980–2015, there was a rapidly increasing trend for both ULL and IPL areas in Chinese UAs (Table 4, Figure 4b,d). ULL increased by 18,508 km^2, and its expansion rate was 529 km^2/year. It increased by 9831 km^2 in national UAs and 8659 km^2 in regional UAs. IPL increased by 12,563 km^2 and its expansion rate was 359 km^2/year. It increased by 3833 km^2 in national UAs and 8660 km^2 in regional UAs (Table 4). ULL area in national UAs was larger than those in regional UAs in 2015 (Figure 4d).

(2) During 1980–2015, both APL and EL in Chinese UAs were decreased seriously (Table 4, Figure 4a,c). APL decreased by 33,454 km^2 and its reduction rate was 956 km^2/year. It decreased by 17,295 km^2 in national UAs and 16,136 km^2 in regional UAs. EL decreased by 2249 km^2 and its reduction rate was 64.26 km^2/year. It decreased by 352 km^2 in national UAs and 1867 km^2 regional UAs. The most serious period of APL reduction was during 1990–1995, and then it had a dramatically increasing trend momently from 1995 to 2000 (Figure 4c). On the contrary, there was a steeply increasing trend for EL from 1990 to 1995, and quickly a sharp decrease during 1995–2000 (Figure 4a). All of these dramatically increasing or decreasing trends of APL and EL were affected by Chinese national policies (returning farmland to forest and grassland in 1992, regulations on the protection of prime farmland in 1994, and land management law revision, which set up the world's strictest farmland protection policy, in 1998).

(3) During 1980–2015, RLL were increased steadily (Table 4, and Figure 4e). RLL increased by 7175 km^2. It increased by 4384 km^2 in national UAs and 2786 km^2 in regional UAs.

Table 4. Variation rates of ecology–production–living land area during 1980–2015.

	1980–1990	1990–1995	1995–2000	2000–2005	2005–2010	2010–2015	1980–2015
Variation rate of ecology land area (km^2/year)							
All	69.80	1757.20	−1953.80	−21.60	−106.20	−265.00	−64.26
National	84.80	1492.60	−1410.80	−140.00	−88.60	−93.20	−10.06
Regional	−12.00	258.00	−538.20	117.60	−17.80	−169.00	−53.34
Variation rate of industrial production land area (km^2/year)							
All	104.90	288.40	30.80	497.20	426.80	1059.60	358.94
National	−4.00	136.20	9.00	207.80	213.00	208.60	109.51
Regional	109.60	146.60	19.60	286.60	212.20	847.80	247.43
Variation rate of agricultural production land area (km^2/year)							
All	−280.20	−3454.20	1841.80	−2030.60	−1037.80	−1449.60	−955.83
National	−102.50	−2886.20	1579.80	−1000.00	−505.40	−442.20	−494.14
Regional	−169.50	−575.80	253.00	−1027.00	−531.80	−1006.60	−461.03
Variation rate of urban living land area (km^2/year)							
All	159.50	1084.80	7.60	1314.00	554.40	421.80	528.80
National	44.40	719.00	−56.80	763.80	266.20	185.20	280.89
Regional	115.00	363.60	65.60	549.60	287.80	235.20	247.40
Variation rate of rural living land area (km^2/year)							
All	33.30	376.20	253.20	329.40	149.20	260.40	205.00
National	−17.40	426.60	25.00	184.80	125.80	149.40	125.26
Regional	50.70	−52.60	230.20	144.20	23.20	110.80	79.60

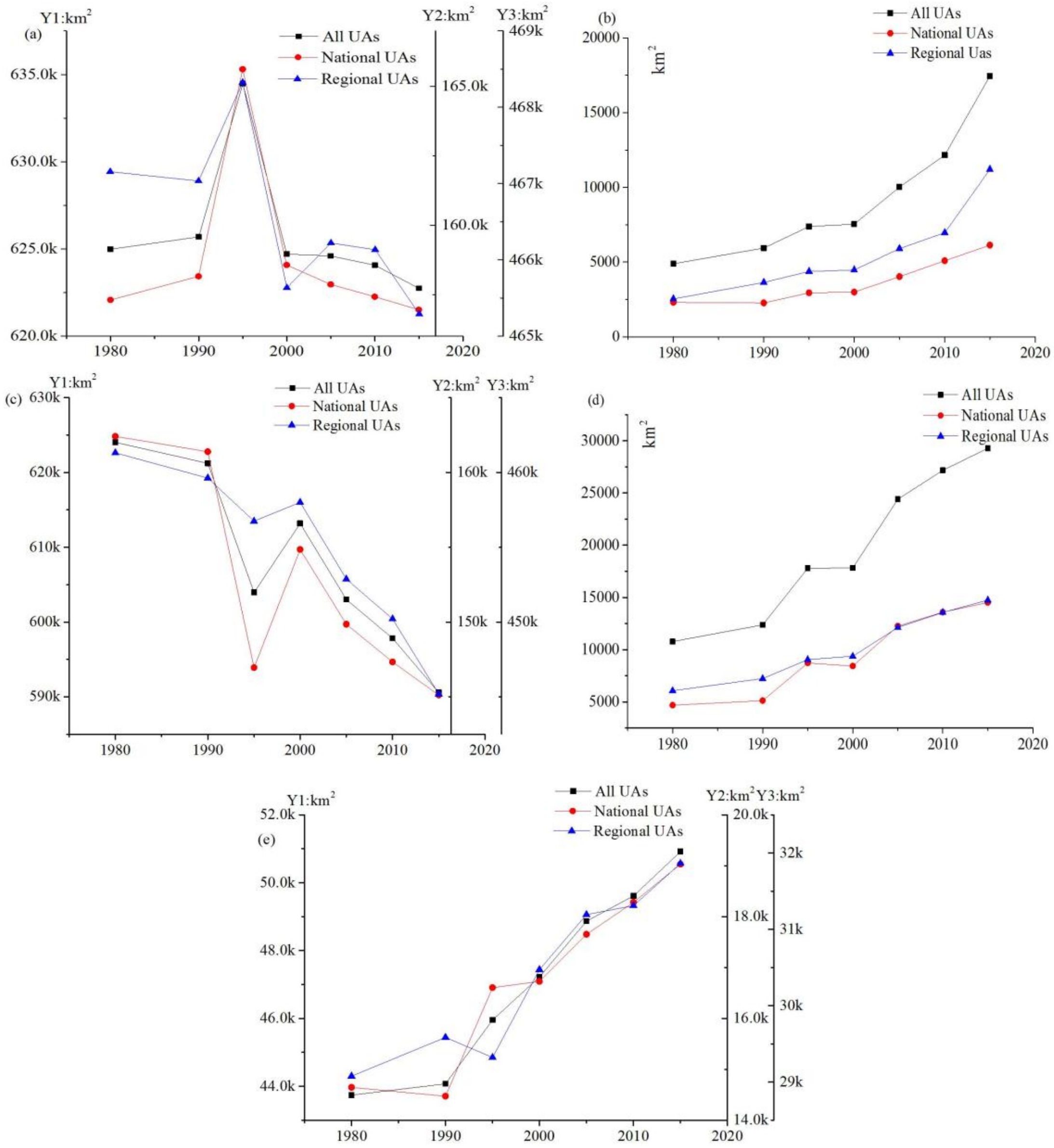

Figure 4. Area variations of EPL in Chinese urban agglomerations (UAs) from 1980 to 2015: (**a**) ecology land (EL); (**b**) industrial production land (IPL); (**c**) agricultural production land(APL); (**d**) urban living land (ULL); and (**e**) rural living land (RLL). Notes: Y1-axis, Y2-axis, and Y3-axis in (**a**,**c**,**e**) represent UAs areas, national UAs areas and regional UAs areas, respectively.

4.1.2. ULL and IPL Changes in Different UAs

We also analyszed ULL and IPL in different UAs, as can be seen in Figure 5:

(1) In 2015, MYT had the largest IPL area, which was up to 3218 km². The most rapid period of its expansion was during 2010–2015. As to different UAs, the rank (from high to low) of IPL area was MYT, BTH, SDP, YRD, WTS, CC, PRD, CSL, CP, and GZ in 2015. GZ had the smallest IPL area, which was only 355 km². There were different growth rates in different UAs, and it is possible because of different UAs' functions and the impacts of national policies.

(2) In 2015, YRD had the largest ULL area, 6276 km², followed by BTH and PRD, while GZ had the smallest ULL area, only 804 km².

(3) There was slow growth or negative growth of IPL and ULL for all UAs during 1995–2000.

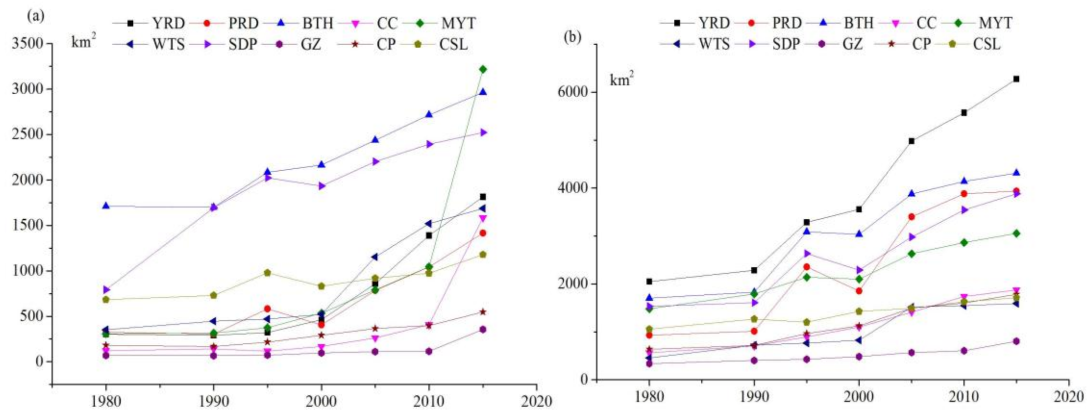

Figure 5. Area variations of industrial production land (IPL) and urban living land (ULL) in different UAs from 1980 to 2015: (**a**) IPL; and (**b**) ULL. Note: Please refer to Figure 2 for an explanation of the UAs abbreviations.

4.2. Spatial—Temporal Patterns of EPL

Figure 2 shows the spatial patterns of EPL in Chinese UAs in 2015. As can be seen in Figure 2, EL and APL had a higher proportion of land area than the others. In 2015, the proportions of EL, APL, RLL and ULL were 47.25%, 44.81%, 3.86%, and 2.22%, respectively.

Based on above analysis, we can conclude that the ULL and IPL were increased rapidly, while the EL and APL were decreased seriously in Chinese UAs during 1980–2015. In order to explore the spatial growth patterns of ULL and IPL, we selected eastern BTH, central GZ, northeast CSL, and western CC to map the spatial pattern variation of ULL and IPL. As can be seen in Figure 6:

(1) There were different spatial patterns of expansions in different cities. Most cities showed a "standing pancake" feature, and the growth patterns showed a "Concentric circle" feature.
(2) There were also different expansion rates of ULL and IPL in different UAs: the national UAs including YRD, BTH, and PRD had higher expansion rates than the regional UAs. As to different regional zones, the growth pattern of ULL and IPL showed spatial heterogeneity. The growth rates ranked from high to low were as follows: eastern UAs, central zone UAs, western UAs and northeast UAs. However, as time goes on, the hot spots of rapid growth gradually moved from the eastern UAs to the central and western UAs.
(3) All of the ULL and IPL areas in core cities were larger than those in non-core cities, such as Beijing and Tianjin cities in BTH; Shenyang city in CSL; and Chengdu and Chongqing cities in CC. It is clear that the population and industrial resources continue to concentrate in large cities.

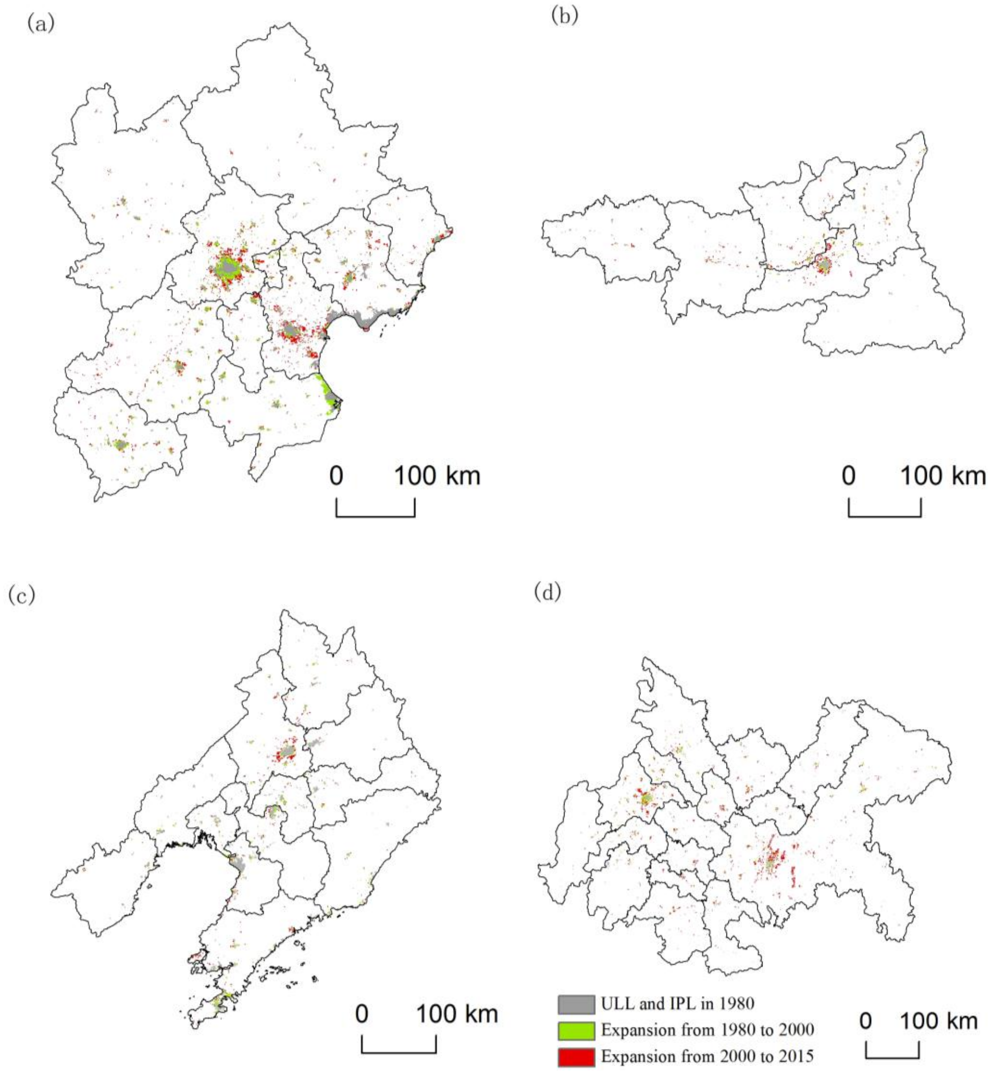

Figure 6. Spatial variation map of urban living land (ULL) and industrial production land (IPL) during 1980–2015: (**a**) Beijing-Tianjin-Hebei urban agglomeration (BTH); (**b**) Guanzhong urban agglomeration (GZ); (**c**) Chengdu-Chongqing urban agglomeration (CC); and (**d**) Central and southern Liaoning urban agglomeration (CSL).

4.3. Impacts of Policies on the Changes of EPL

China has implemented a series of policies to stimulate socioeconomic development and protect the ecological environment over the past 35 years, including reform and opening up in 1978, setting up special economic zones in four eastern coastal cities in 1980, further extending the coastal special economic zones in 1989, returning farmland to forest and grassland in 1992, regulations on the protection of prime farmland in 1994, joining WTO in 2001, China western development plan in 2000, northeast area revitalization plan in 2004, rising of central China plain in 2006, and promoting UAs as the main spaces for pushing forward the new type urbanization after 2006. In order to analyze the impacts of these policies on the changes of EPL in UAs, we divided 10 UAs into eastern UAs, central UAs, western UAs and northeastern UAs (Table 3). Figure 7 illustrates the impacts of policies on the changes of EPL in UAs:

(1) With the implementation of reform and opening up in 1978, Chinese urbanization and industrialization accelerated rapidly. Setting up special economic zones in four eastern coastal cities in 1980 and further extending the coastal special economic zones in 1989 had greatly stimulated the rapid development of the eastern coastal UAs. There was a substantial increasing trend of ULL and IPL in eastern UAs (Figure 7b), and the growth rate in eastern UAs was faster than that in central zone, western zone, and northeastern UAs.

(2) With the implementation of returning farmland to forest and grassland in 1992, there was a significant reduction in APL from 1990 to 1995. The reduction rate of APL was 3454 km2/year in this period, while the expansion rate of EL was 1757 km^2/year. There were continuous transformations from APL to EL and ULL during 1990–1995 (Figure 7a and Table 4). On the contrary, regulations on the protection of prime farmland in 1994 had greatly stimulated a great increase in APL, which was increased by 9209 km^2 from 1990 to 1995. Moreover, the implementation of cultivated land conservation contributed to the serious reduction of EL and constrained the expansion of ULL and IPL in this period (Figure 7a–d and Table 4).

(3) After China joined the WTO in 2001, ULL and IPL accelerated rapidly again from 2000 to 2005 (Figure 7b–e). Western development plan in 2000 promoted the increasing of IPL and ULL in western UAs from 2000 to 2010 (Figure 7c). Northeast area revitalization plan in 2004 also promoted the increase of ULL in northeastern UAs from 2005 to 2010 (Figure 7e). Rising of Central China Plain in 2006 had little effects on the expansion of IPL and ULL. On the contrary, there was a decrease trend of IPL and ULL during 2005–2010 (Figure 7d).

(4) With the promoting UAs as the main spaces for pushing forward the new type urbanization after 2006, China had implemented a series of policies to stimulate the development of UAs (Figure 7). All of these national policies had brought new opportunities for the socioeconomic development of UAs, especially for western, central, and northeastern UAs. As a result, IPL in western, central, and northeastern UAs were increased rapidly from 2010 to 2015 (Figure 7c–e and Table 4).

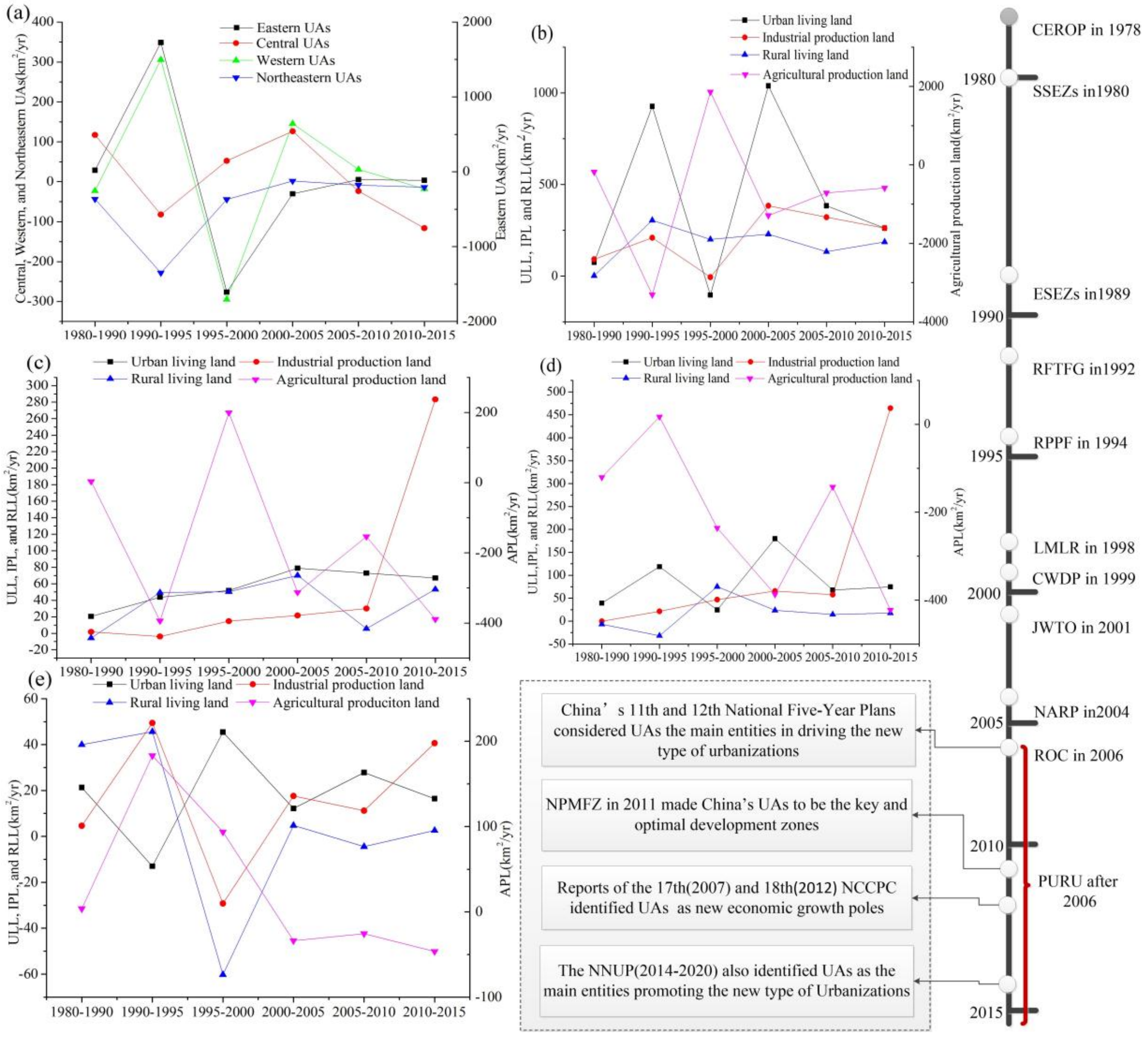

Figure 7. Impacts of policies on EPL changes from 1980 to 2015: (**a**) ecology land; (**b**) eastern UAs; (**c**) western UAs; (**d**) central UAs; and (**e**) northeastern UAs. Note: Abbreviations for Chinese policies: reform and opening up (CEROP); setting up special economic zones in four eastern coastal cities including Shenzhen, Zhuhai, Shantou and Xiamen (SSEZs); further extending the coastal special economic zones (ESEZs); returning farmland to forest and grassland (RFTFG); regulations on the protection of prime farmland (RPPF); land management law revision (LMLR); China western development plan (CWDP); economic development stimulus after joining WTO (JWTO); northeast area revitalization plan (NARP); rising of central China plan (ROC); promoting UAs as the main spaces for the new type urbanization (PUAU); National Plan for Major Function-Oriented Zones (NPMFZ); National Congress of the Communist Party of China (NCCPC); and National New-type Urbanization Plan (NNUP). Chinese policy implications: Special economic zones of China (SEZs): The government of China gives SEZs special (more free market-oriented) economic policies and flexible governmental measures. This allows SEZs to utilize an economic management system that is more attractive for foreign and domestic firms to do business in than the rest of Mainland China.

4.4. Impacts of Socioeconomic Factors on the Changes of EPL

4.4.1. Impacts of Population and GDP on the Changes of ULL and IPL

(1) Non-agricultural population (NAP): NAP increased from 90.47 million people in 1980 to 371.47 million people in 2015 and had an increase of ~3.11 times. It had a constant stimulation for the increase in ULL and IPL. The correlation coefficient R^2 was 0.88 (Figure 8a), and 0.98 (Figure 8b) between NAP and ULL area, and NAP and IPL area, respectively. In addition, there was a good consistent increase trend both of them (Figure 9a,b).

(2) Non-agricultural GDP (combined second and tertiary industry GDP, NAGDP): The rapid increase in NAGDP had an effective impact on the expansion of ULL, and it increased from 441.8 billion Yuan in 1980 to 43,011 billion Yuan in 2015, which had an increase of ~96.35 times. The correlation coefficient R^2 between NAGDP and ULL area was 0.80 (Figure 8c), but the growth trend between them was not completely consistent, especially in periods of 1995–2000 and 2000–2005. It implied that to some extent, the EPL changes in UAs were more influenced by the policies than the market economy. The rapid increase in NAGDP also greatly stimulated the increase in IPL. The correlation coefficient R^2 between NAGDP and IPL area was 0.96 (Figure 8d) and there was a consistent growth trend between them, except for the period during 1995–2000.

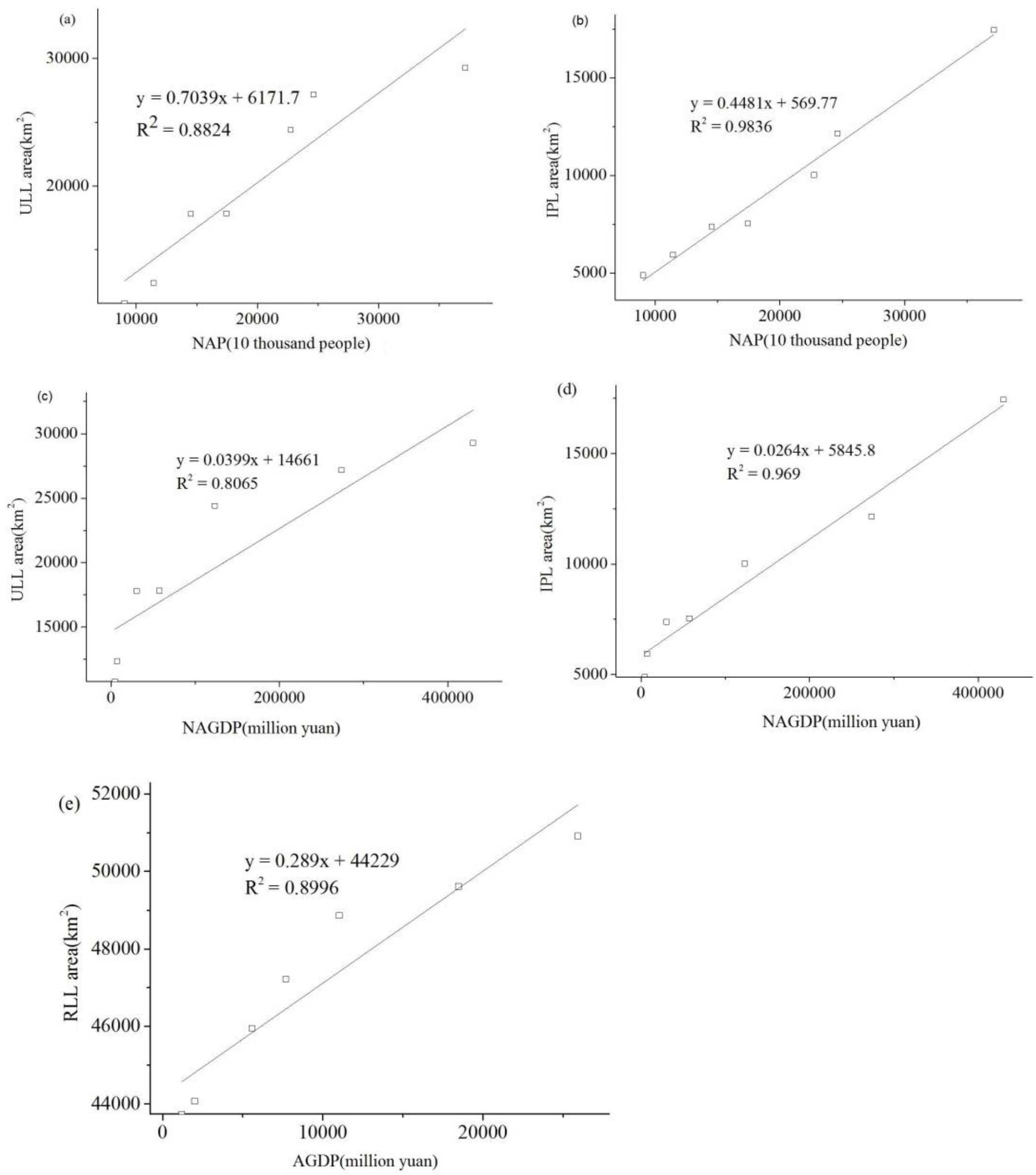

Figure 8. Scatter diagram among non-agricultural GDP (NAGDP), non-agricultural population (NAP), agricultural GDP (AGDP) and EPL areas: (**a**) ULL and NAP; (**b**) IPL and NAP; (**c**) ULL and NAGDP; (**d**) IPL and NAGDP; and (**e**) RLL and AGDP.

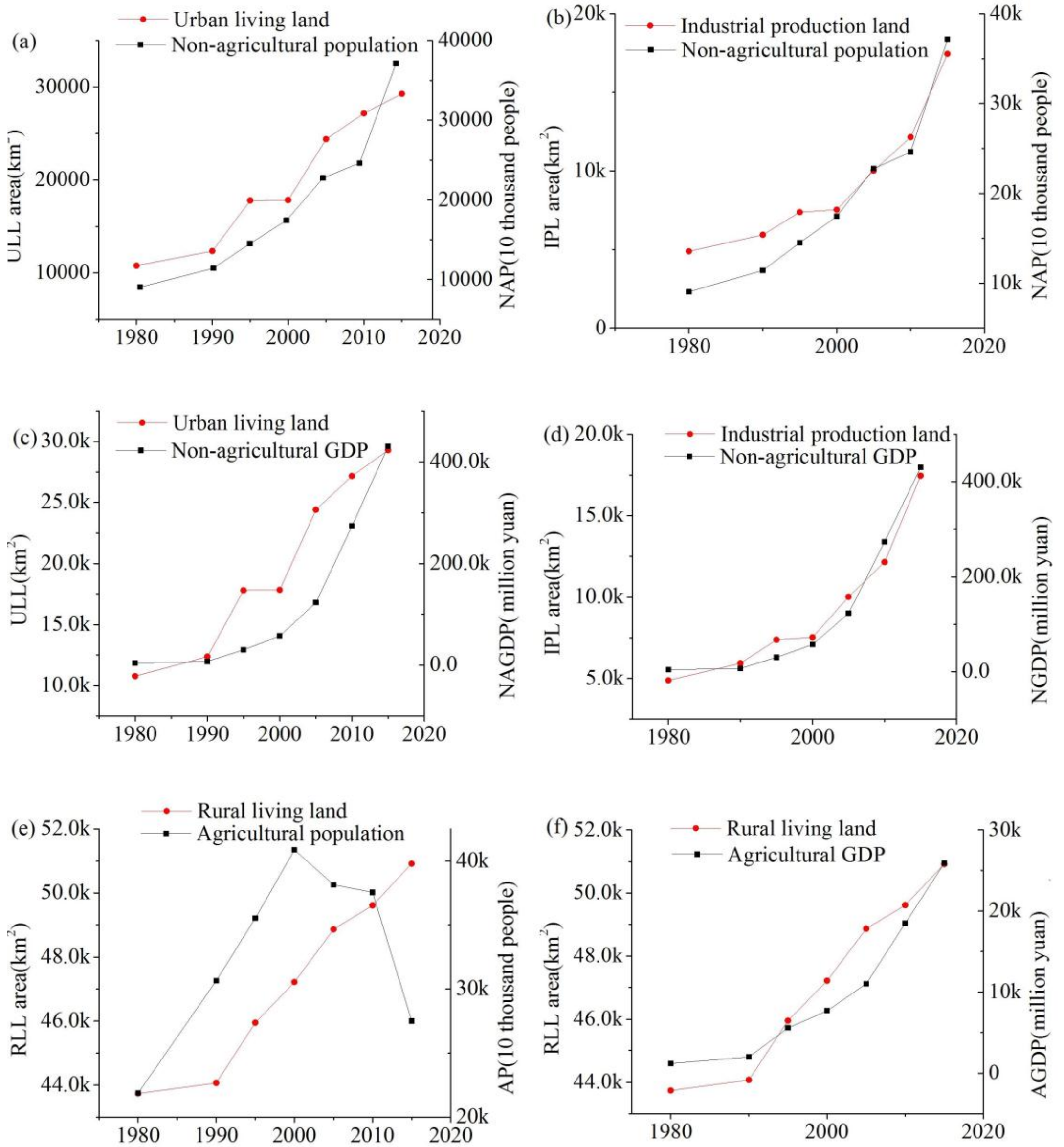

Figure 9. Trend chart among population, GDP and EPL changes: (**a**) ULL and NAP; (**b**) IPL and NAP; (**c**) ULL and NAGDP; (**d**) IPL and NGDP; (**e**) RLL and AP; and (**f**) RLL and AGDP.

4.4.2. Impacts of Population and GDP on the Changes of RLL and APL

(1) Agricultural population (AP): The AP increased from 218.85 million people in 1980 to 275.11 million people in 2015, and had an increase by 56.26 million people. It had a constant stimulation for the increase in RLL. However, the correlation coefficient R^2 between them was low. As can be seen in Figure 9e, the growth trend was consistent before 2000. With the rapidly accelerated urbanization after 2000 in China, there was a sharp decrease in AP. The correlation coefficient R^2 between APL and AP was also low during 1980–2015.
(2) Agricultural GDP (AGDP): The rapid increase in AGDP had greatly promoted the growth of RLL. It was increased from 119.9 billion Yuan in 1980 to 25,911 billion Yuan in 2015, and had an increase of ~20.61 times. As can be seen in Figure 8e, the correlation coefficient R^2 was high between AGDP and RLL, which was up to 0.89, and the growth trend between them was consistent (Figure 9f). The correlation coefficient R^2 between APL area and AGDP was low during 1980–2015. This implied that APL changes were mainly affected by policies.

5. Discussion

5.1. Spatial-Temporal Trajectories of EPL during 1980–2015

During 1980–2015, the spatial-temporal trajectories of EPL were the rapid increase in ULL and IPL and the serious reduction in APL and EL. The results in this paper showed that ULL had increased by 18,508 km^2, and its average expansion rate was 529 km^2/year. The IPL had increased by 12,563 km^2, and its average expansion rate was 359 km^2/year.

The combined ULL and IPL expansions pattern had shown a spatial heterogeneity. That is mainly reflected in three aspects as follows: First, at the national-scale, the growth rate in different UAs was different. The expansion rates of ULL and IPL ranked from high to low were as follows: eastern, central, western, and northeastern UAs. However, as time goes on, the hot spots of rapid growth gradually moved from the eastern UAs to the central and western UAs. Second, at the UA-scale, ULL and IPL area and its expansion rates in core cities were higher than those in non-core cities. Finally, at the city-scale, there were different spatial expansions in different cities. Most cities showed a "standing pancake" feature, and the growth pattern showed a "Concentric circle" feature.

5.2. The Main Driving Factors of EPL Spatial-Temporal Changes

The analysis in this paper showed that the spatial-temporal changes of EPL was mainly influenced by the national policies, population and market economy. The implementation of reform and opening up in 1978, joining WTO in 2001, all regional development policies and promoting UAs as the main spaces for pushing forward the new type urbanization after 2006, had largely stimulated the increasing in ULL and IPL. While the regulations on the protection of prime farmland in 1994 had greatly stimulated the increasing of APL and rapidly constrained the expansion of ULL and IPL, our conclusion is mainly consistent with the previous research results [26,27].

Population increasing and economic development also effectively stimulated the expansion of ULL and IPL in a certain extent. While the inconsistent growth trend between GDP and the expansion of ULL and IPL implied that EPL changes in Chinese UAs was more affected by the national policies.

5.3. The Rationality of Our EPL Classification System and the Effectiveness of Chinese Remotely-Sensed LUCC Product-Based Research

In this paper, we divided EPL into EL, IPL, APL, ULL and RLL due to Chinese urban–rural dual structure. Our results showed that our classification system can accurately describe the spatial-temporal trajectories and drivers of EPL changes in Chinese UAs. Thus, this classification system is rational for the analysis of the EPL spatial-temporal trajectories in Chinese UAs.

Our research is a typical application case of Chinese remotely-sensed LUCC product. We intensively confirm the effectiveness of Chinese remotely-sensed LUCC product in the EPL study.

5.4. Policy Enlightenment of EPL Spatial-Temporal Trajectories in Chinese UAs

Since reform and opening up in 1978, the rapid expansion of ULL and IPL occupies a large number of high-quality APL and EL. It caused a series of ecological and environmental problems in UAs. UAs had become the high-risk and sensitive zones of haze. There was serious contradiction between socioeconomic development and the protection of APL and EL. The policy of returning farmland to forest and grassland in 1992 and regulations on the protection of prime farmland in 1994 implied that there was also a conflict between EL and APL. These reflect the functional diversity of the land use system. The spatial-temporal changes of EPL in the UAs also reflect the cooperation and competition among different functions and objectives [28,29]. It implied that the UAs in China has the same phenomena of "multi-planning" among different government departments. (In China, there are many different plannings from many different government departments. These different plannings, such as Ecological Environment Protection Planning, Economic Development Planning, and so on, have many conflicts. For example, a region cannot be exploited according to Ecological Environment Protection Planning, but it must be exploited for economic development according to Economic Development Planning. Thus, Chinese government put forward a policy of multi-planning integration to avoid this phenomenon of multi-planning. However, the implementation of multi-planning integration is currently only at city-scale, and not UA-scale.) The cooperation and integration of socioeconomic development planning, eco-environmental protection planning and other planning are the basic premise for the UAs' land pattern optimization. It is worth considering how to realize the "multi-planning cooperation" or the "multi-planning fusion" at the UA-scale.

The successful experience of international UAs in developed countries shows that the higher degree of marketization, the higher degree of development of UAs [8]. Chinese UA development has long been intervened too much by national policies. The analysis of this paper shows that the changes of EPL in Chinese UAs were also affected by the national policies in a great extent. The pattern of EPL in the future should follow the law of market operation and further develop the market mechanism in the UA land development.

6. Conclusions

Taking 10 UAs as study area, we first divided EPL into EL, IPL, APL, ULL and RLL. We analyzed the spatial-temporal trajectories and driving factors of EPL in Chinese UAs since reform and opening up in 1978. The main conclusions are as follows: (1) The spatial-temporal trajectories of EPL were the rapid expansion of ULL and IPL and the serious reduction of APL and EL from 1980 to 2015. (2) The combined ULL and IPL expansions pattern had shown a spatial heterogeneity. The expansion rates of ULL and IPL ranked from high to low were as follows: eastern, central, western, and northeastern UAs. However, as time goes on, the hot spots of rapid growth gradually moved from the eastern UAs to the central and western UAs. (3) The spatial-temporal changes of EPL were mainly influenced by the national policies, population and market economy. Further, the inconsistent growth trend between GDP and EPL changes implied that EPL changes in Chinese UAs were more affected by national policies. (4) The multi-planning integration and market mechanism in the structure of land use should be strengthened at UA-scale.

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Nomenclature

AGDP	agricultural GDP
AP	agricultural population
APL	agricultural production land
BTH	Beijing-Tianjin-Hebei UA
CC	Chengdu-Chongqing UA
CP	Central Plain UA
CPC	National Congress of the Communist Party of China
CSL	Central and southern Liaoning UA
EL	ecological land
EPL	Ecology-Production-Living Land
ETM+	Enhanced Thematic Mapper
GDP	Gross Domestic Product
GZ	Guanzhong UA
IPL	industrial production land
LUCC	Land-Use and Land-Cover Change
MYT	Middle Yangtze UA
NAGDP	non-agricultural GDP (combined second and tertiary industry, NAGDP)
NAP	non-agricultural population
OLI	Operational Land Imager
PRD	Pearl River Delta UA
RESDC	Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences
RLL	rural living land
SDP	Shandong Peninsula UA
TM	Thematic Mapper
UA	urban agglomeration
UAs	urban agglomerations
ULL	urban living land
WTO	World Trade Organization
WTS	Western Taiwan Strait UA
YRD	Yangtze River Delta UA

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