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Assessment on China's urbanization after the implementation of main functional areas planning

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1 **Assessment on China's Urbanization after the Implementation of**

2 **Main Functional Areas Planning**

3 **Abstract:** China has implemented main functional areas planning (MFAP) since 2010,

4 which is essential for improving the efficiency of land space utilization and achieving

5 sustainable urban development. Quantitative assessments of the urban development

6 levels (UDLs) at the county level across China after the implementation of MFAP have

7 not been well-documented. In this study, a unified indicator system was developed, and

8 the UDLs of 2850 counties in China after MFAP implementation were evaluated. The

9 results showed that MFAP played a positive role in urban development in China. The

10 UDLs in China generally increased but showed obvious spatial differences. The higher

11 UDLs were mostly found in the counties in the five urban belts, which reflects the

12 overall urban layout of China. The UDLs were generally low in the western counties in

13 comparison with those in the eastern part of China. The differences in the UDLs from

14 east to west were greater than those from north to south. Moreover, the differences in

15 the UDLs presented a spatial agglomeration effect. This study could offer insight into

16 the refinement of MFAP in China and sustainable urban development in developing

17 countries.

18 **Key words:** Urbanization; Main Functional Areas Planning; Assessment; China;

19 Sustainable development

1. Introduction

21 China has experienced dramatic urbanization and extensive urban expansion since

22 the reform and opening-up (Wang et al., 2019; Yang and Jiang, 2018) while also

23 suffering increasing population growth and severe resource constraints in the regional

24 environment (Bai, 2014; Gaughan et al., 2016; Li, B. et al., 2016; Li, J. et al., 2018;

25 Long et al., 2018), which results in serious contradictions between plans and

26 maladjusted spatial management (Zhao, Y. et al., 2018). To effectively plan the

27 distribution of the population and economy, improve the efficiency of space utilization

28 and realize the goal of sustainable development, China has implemented main

29 functional areas planning (MFAP) (Fan et al., 2012b; Fan et al., 2019; Liu et al., 2017).

30 Urban development, as one of the critical topics emphasized in MFAP, has sparked

31 increasing attention (Du et al., 2014; Guan et al., 2018).

32   Urban development is mostly accompanied by population agglomeration,

33 socioeconomic development and urban land expansion (Li, G. et al., 2018; Liu, Y. et al.,

34 2018; Ramachandra et al., 2015; Wang et al., 2019). Researchers have been devoted to

35 evaluating urban development from different perspectives. Numerous studies have

36 focused on comparing the differences in urban development at different territorial levels

37 based on data from multiple years (Bai et al., 2012; Gao et al., 2015; Kuang et al., 2016;

38 Li, G. et al., 2018; Shu et al., 2018; Zhan et al., 2018). Methods such as the

39 comprehensive index system, quadrant plots method, exploratory spatial data analysis,

40 correlation analysis, stepwise regression and the McKinsey matrix have been widely

41 adopted (Chen et al., 2013; Shen et al., 2015; Zhang, W. et al., 2018; Zhang, Y. et al.,

42 2018; Zhao and Wang, 2018; Zhao, Y. et al., 2018). Undoubtedly, scholars have made

43 progress in urbanization evaluations. Since administrative variables play important

44 roles in the management of urban development in developing countries (Fang et al.,

45 2016; Vojnovic, 2014), previous studies must be expanded to understand the strategic

46 requirements of urban development (Fang et al., 2016; li and Liu, 2019; Wang, Z. et al.,

47 2018; Zou et al., 2016). MFAP clearly shows that the core of county-level urban

48 development should focus on concentrated distributions of industry, population and

49 urban spaces (Fan et al., 2012a); however, the county-level urban development across

50 China after MFAP was released has not been systematically quantified (Chen et al.,

51 2013; Fan et al., 2019; Yu et al., 2018; Zhou et al., 2018). The current studies that have

52 evaluated urban development based on county-level units have been mostly restricted

53 to typical areas and depend on multiple indicators (Liu and Wei, 2014; Xiao et al., 2018;

54 Yang and Jiang, 2018; Zhou et al., 2015), making county-level data collection across

55 the whole nation difficult.

56 The growing interest in evaluating urban development through the consideration

57 of policy demands is also observed worldwide and is mainly focused on the

58 establishment of comparable indicators for sustainable urban assessments (Dhakal and

59 Imura, 2003; Holden, 2006; Klopp and Petretta, 2017; Meijering et al., 2018; Moreno

60 Pires et al., 2014; Yigitcanlar and Lönnqvist, 2013), creation of a global city policy

61 database (Rozhenkova et al., 2019; Townsend, 2015), analysis of official documents

62 (Medina and Huete García, 2019), and design of survey experiments (Pleger et al.,

63 2018). However, quantitative evaluation of urban development across the whole nation

64 linked to policy metrics is still challenging due to a lack of consensus on the correct

65 approach (Hák et al., 2016; Hasan and Satterthwaite, 2005; Parnell, 2016). Given that

66 governance management systems are relatively weak in most developing countries and

67 that disorganized urbanization is increasingly prominent (Bren d'Amour et al., 2017),

68 unified measurements of urban development that translate policy targets are urgently

69 needed (Al shawabkeh et al., 2019; Colléony and Shwartz, 2019; Ouyang et al., 2016;

70 Ramachandra et al., 2015; Yue et al., 2019; Zhang et al., 2012).

71   Thus, this study attempted to develop unified indicators that could be comparable

72   at the county scale across China, adequately reveal the regional disparity in urban

73   development, and directly inform decision-making in MFAP and the sustainable

74   development in developing countries (Zhang et al., 2015). The specific objectives were

75   1) to develop an index system for the assessment of urban development levels (UDLs)

76   to satisfy multiple needs of the county-scale spatial units, the accessibility of data and

77   ability to depict policy targets; 2) to assess the temporal changes in the UDLs from 2009

78   to 2015 in China; 3) to compare multi-scale regional differences in the UDLs in the

79   years 2009, 2012, and 2015; and 4) to propose policy recommendations to serve further

80   urban development and spatial regulation in China.

81   **2. Methodology**

82   2.1 Study area

83   The study area included 2850 counties, districts and banners, except Hong Kong,

84   Macao and Taiwan, which lack data in China. The "two-horizontal" spatial urbanization

85   pattern (See Fig. S1) included the Asia-Europe and ridge passageway, which starts from

86   Lianyungang city and ends in Alataw pass (H1), and the passageway along the Yangtze

87   River in China (H2). The "three-longitudinal" spatial urbanization pattern included the

88   coastal passageway (L1), the "Beijing-Harbin to Beijing-Guangzhou" passageway (L2),

89   and the "Baotou to Kunming" passageway (L3). In MFAP, the national land was divided

90   into four categories, which are the main functional areas (MFAs) (See Fig.1). The

91   classification of MFAs are displayed in Fig. S2. There are four geographical great-areas

92   in terms of provincial administrative level in China, which are eastern China covers 10

provincial level administrative units (Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong and Hainan), central China covers 6 provincial level administrative units (Shanxi, Henan, Anhui, Jiangxi, Hunan and Hubei), western China covers 12 provincial level administrative units (Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Gansu, Shaanxi, Inner Mongolia, Ningxia, Xinjiang, Qinghai and Xizang)and northeastern China covers 3 provincial level administrative units (Liaoning, Heilongjiang and Jilin).

2.2 Data

The GDP and urban population of each county were obtained from statistical yearbooks. The areas of each county were obtained from the Ministry of Civil Affairs of the People's Republic of China (http://www.mca.gov.cn/). The national and provincial MFAP (2010–2020) was obtained from the official government website (https://www.ndrc.gov.cn/). The construction land areas were interpreted with land use data downloaded from the Resource and Environment Data Cloud Platform, Institute of Geographic Sciences and Natural Resources Research (http://www.resdc.cn/) (see Table S1, S2 for full details). We also carried out field surveys in Ningxia, Shaanxi, Gansu, Fujian, Beijing, Zhejiang, Hainan, Inner Mongolia and Hubei.

2.3 Methods

2.3.1 Comprehensive index evaluation method

The comprehensive index evaluation method is widely used to assess the status of urban development (Bai et al., 2018; Wang et al., 2013; Yu et al., 2014; Zhou et al., 2015). Indexes can reflect the evolutionary process of urban systems that are induced

115   by the dynamic interactions between related human activities (Zhang et al., 2019; Zhao

116   and Wang, 2018). Currently, nationwide assessments on UDLs based on comprehensive

117   index evaluation method is still lacking and the basic unit mostly concentrated at the

118   municipal level and the provincial level (Shu et al., 2018; Zhao and Wang, 2018).

119   Although UDLs assessment at county level on specific provinces have relatively

120   systematic frameworks, it is difficult to scale up single case studies to the whole national

121   due to the limitations on universality of the index system and availability of data (Zhou

122   et al., 2015; Wang et al., 2019). We built on this background and performed our work,

123   which satisfied multiple needs of the county-scale spatial units, data accessibility and

124   the ability to depict the requirements of the UDLs in MFAP. The unified county-level

125   evaluation system, when compared to nation-level and province-level evaluation

126   systems, is advantageous to reflect the UDLs of county-level administrations directly,

127   quantify the regional disparity of UDLs adequately, and realize the connection of macro

128   scale and micro scale on management targets. The evaluation system mainly included

129   3 main steps.

130   First, the evaluation indicator system and the county-scale database were

131   developed. Urban development is a complex dynamic process that is accompanied by

132   multidimensional factor changes (Chen et al., 2010; Tan et al., 2018; Xiao et al., 2018;

133   Zhao and Wang, 2018). Previous studies have shown that the evaluation of UDLs

134   mainly focuses on the four dimensions of population growth, economic development,

135   life improvement and spatial expansion (Addanki and Venkataraman, 2017; Chen et al.,

136   2018; Chen et al., 2010; Michael et al., 2014). The selection of the indexes in this study

137   was based on the literature and our repeated understanding of MFAP (Wang et al., 2019).

138   Considering that the areas with high development levels mainly show the characteristics

139   of providing industrial products and service products and having high degrees of

140   population agglomeration and development degree in MFAP, a four-dimensional

141   evaluation system was set up in this paper (see Table 1). Full details about index system

142   can be found in Supplementary materials. Fig. S3 displays the spatial distributions of

143   the third-level indexes. Multicollinearity diagnosis was used to exclude the problem of

144   colinearity. All VIFs of the indicators were lower than 10, implying that there is no

145   collinearity among the indicators (Zhao, J. et al., 2018).

146   Second, we normalized the indicators into comparable units and computed the

147   weights. Considering that different indicators have different dimensions and

148   magnitudes and different effects on performance evaluation, a normalization process

149   was necessary. The indicators were standardized using Equations (1) and (2) so that all

150   indicators had values between 0 and 1.

151   For the positive indicators, a larger value indicates an improved urbanization level.

152
$$X_{ij}^{'} = f_a + (f_b - f_a)\frac{X_{ij} - X_{\min}}{X_{\max} - X_{\min}} \tag{1}$$

153   For the negative indicators, a smaller value indicates an improved urbanization

154   level. Therefore, Equation (2) can be obtained as follows:

155
$$X_{ij}^{'} = f_b + (f_a - f_b)\frac{X_{\max} - X_{ij}}{X_{\max} - X_{\min}} \tag{2}$$

156   where f_a and f_b are adjustable parameters that help the gathered distribution

157   normalize values; n is the number of indicators; and m is the number of sample cases;

158   X_{ij} is the value of index j in unit i; and X_{min} and X_{max} are the minimum and

159   maximum values of index j, respectively. X'_{ij} is the normalized value of index j and

160   ranges from 0 to 1.

161   In the evaluation indicator system, each indicator plays a role in and contributes to

162   UDLs to varying degrees. It was necessary to determine the weight of each indicator.

163   The entropy method has been widely used in urbanization assessment because it can

164   eliminate expert subjectivity to a large extent (Chen et al., 2010; He et al., 2017; Li and

165   Li, 2014; Li et al., 2012; Liu, N. et al., 2018; Zhou et al., 2015). The entropy method is

166   based on information theory. Information entropy is the measurement of the degree of

167   disorder within a system, which can be further applied to measure the amount of useful

168   information of the data provided (Amiri et al., 2014). The smaller the information

169   entropy is, the lower the degree of disorder in information, the greater the utility value

170   of the information, and the greater the index weights (Liu and Wei, 2014; Zou et al.,

171   2006). According to the entropy value, the weight of the index could be calculated. Thus,

172   the entropy method was adopted to determine the weight of each indicator. The steps

173   were as follows (formulas (3)-(6)):

174
$$Y_{ij} = \frac{X'_{ij}}{\sum_{i=1}^{m} X'_{ij}} \quad (3)$$

175
$$e_j = -k \sum_{i=1}^{m} (Y_{ij} \ln Y_{ij}) \quad (4)$$

176
$$d_j = 1 - e_j \quad (5)$$

177

$$w_j = \frac{d_j}{\sum\limits_{j=1}^{n} d_j}$$

(6)

178   where Y_{ij} is the ratio of index j in unit i, m is the number of units to be assessed,

179 k is a constant and $k = \frac{1}{\ln m}$. e_j is the information entropy, which represents the

180 amount of information carried in index j. Specifically, the greater the amount of

181 information, the higher the entropy. d_j is the redundancy of the information entropy,

182 n is the number of indexes, w_j is the weight of each indicator and $\sum w = 1$. The

183 weights of the indicators were listed in Table 2.

184   Third, we calculated the urbanization development index and assigned the

185 classifications. F_i represents the performance of the urbanization development index,

186 which can be obtained by the following equation:

187

$$F_i = \sum_{j=1}^{n} \mathrm{x}'_{ij} \times w_j$$

(7)

188   Based on the natural breaks criterion and the real conditions of China, F_i can be

189 classified into 5 levels (see Table 3).

190 2.3.2 Pearson's correlation analysis

191   To identify whether MFAP contributed to urban development from 2009-2015,

192 Pearson's correlation analysis was carried out for the correlation between F_i and

193 ranked the urban development functional importance of 2850 counties with SPSS 21.0

194 software. The rank of urban development functional importance was based on the

195 definitions and requirements of the MFAs. According to the MFAP, the importance of

196 urban development function was generally from high to low in the order of optimal

development areas (ODAs), key development areas (KDAs), major agricultural

production areas (MAPAs) and important ecological functional areas (IEFAs).

Consequently, the numbers "4", "3", "2" and "1" were adopted to represent the ranks

of the urban functional importance of the ODAs, KDAs, MAPAs and IEFs, respectively.

If urban development benefited from the implementation of MFAP, there should be a

positive correlation from 2009 to 2015. Two significance levels (0.05 and 0.01) were

set, and a two-tailed test was performed.

3. Results

3.1 The impacts of MFAP on urban development

Pearson's correlation analysis showed that there was a positive correlation between

F_i and the ranking of urban functional importance of 2850 counties (P < 0.01). From

2009 to 2015, the correlation coefficients were listed as 0.419, 0.420 and 0.423,

respectively. This indicated that the urban development of ODAs, KDAs, MAPAs and

IEFAs was in line with the orientation of MFAP. The MFAP played a positive role in

optimizing urban development from 2009-2015 in China.

3.2 Urban development at the national level

As illustrated in Fig. 2, the UDLs in China showed an overall increasing phase. In

2009, the number of county-level administration regions that reached Class I to Class

III was 1399, which accounted for 49.09% of the regions. In 2015, this number

increased to 1599, which included 56.11% of the total number. In addition, compared

to 2009, the number of counties that reached Class IV and Class V decreased by 31 and

231, respectively, in 2015 (see Table S3).

219   Fig. 3 displays the spatial pattern of the UDLs in China from 2009 to 2015. Overall,

220   the counties in these urban belts, which reflect the overall urban layout of China,

221   showed higher UDLs than those of other regions. In particular, the UDLs rose obviously

222   in the counties of Chongqing, Chengdu, Wuhan, Changsha in H2 and Chongqing,

223   Chengdu, the central parts of Guiyang in L3. In addition, the counties located in

224   Zhengzhou and Xi'an in H1 increased more in higher UDLs. There were no such

225   obvious increases in the counties in Lanzhou, Sining, Urumchi in H1; Harbin,

226   Changchun and Shenyang in L1; and Hohhot and Kunming in L3. The UDLs in county-

227   level administrative areas from 2009-2015 were always high, while the increase in the

228   UDLs was not apparent in the Beijing-Tianjin-Hebei region, Yangtze River delta region

229   and Pearl River delta region in H1. It was observed that the UDLs in the western

230   counties was obviously lower than that in the other three areas, and they were almost

231   all grouped in Class V and had sporadic distributions in the other classes. Conversely,

232   the eastern counties that covered most county-level administrations showed higher

233   UDLs. The increasing rates of county-level administrative units from Class I to Class

234   III in eastern China, central China, western China and northeastern China were 14.93%,

235   35.32%, 37.81% and 11.94% from 2009 to 2015, respectively.

236   It is shown in Fig. 4 that the county-level administrations with the Class I urban

237   development level (UDL) were mostly distributed in H2, L1 and L2. Class II was

238   mainly distributed on H1, L1 and L2. Class III covered most regions of H2, L1 and L2.

239   Class IV was mainly distributed in H2 and L2. For Class V, only those in L3 were

240   relatively obvious in 2009. The number of counties whose UDLs belonged to Class

241   I~III was obviously greater than that in Class IV~V in these five belts. As displayed in

242   Fig. 5, the percentage that the first three levels occupied of the total area of H1, H2, L1,

243   L2 and L3 were 73.52%, 78.78%, 82.35%, 81.78% and 60.00%, respectively, in 2015.

244   When compared to 2009, the increases were 4.07%, 12.17%, 5.93%, 7.32% and 12.91%

245   in Class I to Class III for H1, H2, L1, L2 and L3, respectively (see Table S4).

246   Fig.6 demonstrates the class variations of the UDLs in the 31 provinces in China

247   from 2009 to 2015. The county-level administrativons that regularly included most of

248   the first UDLs were mainly in Guangdong, Henan, Shandong and Jiangsu. The counties

249   that covered the second UDL were mostly distributed in Hebei, Henan, Shandong,

250   Jiangsu and Anhui. The counties that covered the third UDL were mostly distributed in

251   Sichuan, Hebei, Anhui and Hunan. Class IV was mainly present in Guangxi, Henan and

252   Jiangxi. Class V was mainly distributed in Gansu, Guangxi, Guizhou, Heilongjiang,

253   Qinghai, Shanxi, Shaanxi, Sichuan, Xizang, Xinjiang and Yunnan. In addition, the

254   UDLs in 2015 in some provinces, such as Ningxia and Hainan, increased obviously

255   when compared to those in 2009.

256   3.3 Urban development at the MFA level

257   3.3.1 Optimal development areas

258   The ODAs are an important part of the "two-horizontal" and "three-longitudinal"

259   spatial urbanization patterns in China. Fig. 7 illustrates the UDLs of the optimal

260   development zones in China. From 2009 to 2015, the amount variation in the county-

261   scale administrative units with UDLs ranging from Class I and Class III were 31, -16

262   and -15, respectively. The corresponding proportional variations were 12.70%, -6.56%

263 and -6.15%.

264 3.3.2 Key development areas

265   The KDAs are the regions distributed in the new spatial pattern of urbanization

266 and have been planned to focus on industrialization and urbanization. As displayed in

267 Fig. 7, the amount of variation in the county scale administrative units with UDLs

268 changing from Class I and Class V was 57, 2, -11, -23 and -25, respectively. The

269 corresponding proportional variations were 9.86%, 0.35%, -1.90%, -3.98% and -4.33%,

270 respectively.

271 **4. Discussion**

272 4.1 Assessment of the UDLs from 2009 to 2015 in China

273   An evaluation of the policy-related outcomes can shed light on the policy's

274 effectiveness and inform further refinements and management (Al shawabkeh et al.,

275 2019; Liu et al., 2010). The national MFAP indicates that China's spatial governance

276 has transformed towards functional control and upgrades (Fan et al., 2019; Fan et al.,

277 2013). Chinese urbanization processes are facing practical and theoretical challenges

278 that might be more complex than what has been seen previously. Fan et al. (2019)

279 comprehensively described the division process of MFAs and emphasized a timely

280 assessment for responding to the adjustment of MFAP. In this study, we successfully

281 developed a comparable index to facilitate comparisons between counties and to inform

282 the urban management focus for MFAP. County-level administration is an important

283 component of the socio-economic structure and is the basic unit in MFAP in China.

284 MFAP proposed that each county included urban, agricultural, or ecological land space,

which determined its corresponding function (Wang, J. et al., 2018). Quantitative evaluation of the UDLs in 2850 counties in this study intuitively reflected the urban functional status and supplemented our understanding of urbanization.

Generally, MFAP has played a positive role in urban development in China. Counties in the "two-horizontal & three-longitudinal" spatial urbanization pattern showed higher UDLs than those of the other regions, implying that the ODAS and KDAs specifically made contributions to urban development (Li et al., 2017; Shahtahmassebi et al., 2018). Land economic density, the degree of population agglomeration, spatial development intensity and UDLs in the five belts in two directions showed different increases from 2009 to 2015, further suggesting that a noticeable and centralized urban pattern has primarily been constructed in China. However, differences among the regional scales still need to be addressed.

The differences in the UDLs in the east-west direction were greater than those in the north-south direction in China. The proportions of UDLs ranging from Class I to Class III in the five belts in MFAP from the maximum to minimum were L1, L2, H1, H2 and L3 in 2015, while the corresponding increments were L3, H2, L2, L1 and H1 from 2009 to 2015. More efforts would be made in MFAP to narrow the gaps between the UDLs, especially in L3 and H2. The land economic density on H1 increased more apparently than the degree of population agglomeration and spatial development intensity in H1 from 2009 to 2015. This was likely due to the optimization of the population distribution and the control of built-up area expansion in the ODAs, which was consistent with the requirements in MFAP. This aligned with Liu et al. (2017a).

307　Class I was mostly distributed in the relatively developed H2, L1 and L2 in the five

308　belts. H2 covers three urban agglomerations in the Yangtze River delta, the middle

309　Yangtze River basin and the Chengdu-Chongqing region, where the counties with Class

310　I UDLs in 2015 accounted for 52.4%, 22.79% and 17.69%, respectively. The gradual

311　development of the Yangtze River Economic Belt, which accounts for 21% of the total

312　area and more than 40% of the total population and GDP in China, was an important

313　contribution (Liu, Y. et al., 2018). The developed eastern provinces, such as Beijing,

314　Tianjin, Shandong, Shanghai and Jiangsu, that were included in H2, L1 and L2 also

315　offer insights into the highest UDLs (Zhang, W. et al., 2018); the respective proportions

316　of the counties with Class I UDLs were 62.5%, 75%, 100%, and 56.25%. The counties

317　in H2, L1 and L2 contain the majority of the ODAs and KDAs. Even though there were

318　also KDAs on H1 and L3, no ODAs were found, and coupling effects are lacking. The

319　Class II UDLs cover most of the regions in H1, L1 and L2. Unlike H2, H1 covers a

320　longer distance across the east and west, and apparent spatial disparities were present

321　in the UDLs. Class III was mostly distributed in H2 and L2, especially the counties in

322　Harbin, Shenyang and Changchun in the northeast and Chongqing, Chengdu, Wuhan,

323　Changsha and Nanchang. The decrease in the proportion of Class IV on L2 further

324　indicated that the cities, where the horizontal and vertical axes intersected, played key

325　roles in the promotion of the UDLs. The decrease in Class V in L3 after 2009 implied

326　a faster pace of urbanization in the central and western counties. This was consistent

327　with the results of similar studies that supported of urban expansion (Zhao et al., 2015).

328　　　There was a gradual reduction in the distribution with a narrowing gap between

329 the UDLs in the east and those in the west. The proportions of the top three levels of

330 UDLs in the four regions from the maximum to minimum were the eastern counties,

331 central counties, western counties and northeast counties in 2015, while the

332 corresponding increments were listed as the western counties, central counties, eastern

333 counties and northeast counties from 2009 to 2015. Because of the greater area and

334 long-term backward urban development of the western region, more efforts need to be

335 devoted to improving the UDLs in the KDAs of the Lanzhou-Xining area, the northern

336 hillslope area of the Tian Shan Mountains and central-southern Tibet, central Yunnan

337 Province and the "Hohhot, Baotou and Ordos" region. The UDLs in provinces with the

338 top three UDLs were distributed in coastal areas. This was likely due to the existence

339 of a relatively long development history of urbanization in the eastern counties in the

340 ODAs (Fang et al., 2016). However, the concomitant small increment further indicated

341 that although massive urban development has been controlled in the ODAs, the

342 overpopulation and economic volumes still cannot be neglected (Chen et al., 2018). The

343 percentage of counties in the top three UDLs in the KDAs of the Harbin-Changchun

344 area decreased by 11.43% from 2009 to 2015. Although China has made efforts to

345 revitalize the northeastern provinces in recent years, improving the traditional industrial

346 structures in KDAs remains challenging (Mao et al., 2019). The county-level

347 administrative units in capital cities such as Xi'an, Wuhan, Changsha, Zhengzhou and

348 Chengdu played important roles in contributing to the rise in the UDLs (Bai et al., 2018).

349 Meanwhile, these counties were KDAs as well as nodes in the "two-horizontal & three-

350 longitudinal" urbanization spatial pattern, and the induced effect of radiation became

obvious. This was consistent with the idea in MFAP and the new urbanization plan

released in 2014 by China's National Development and Reform Commission (li and Liu,

2019). The apparent increase in the UDLs in Ningxia and Hainan also indicates that the

pilot provinces in MFAP had made progress. Urban-rural development gaps still exist

in provinces such as Sichuan, Henan and Anhui.

The regions were not isolated, and the differences in the UDLs among regions

presented a spatial agglomeration effect (Li, H. et al., 2016), which was closely related

to spatial distance, traffic conditions, and population flow. Without sound transportation

networks, it may take longer for materials and the population to flow between distant

regions, which restrains the development of regional linkages (Chandra and Vadali,

2014). However, the agglomeration features are unidirectional and polarizing. The land

economic density, degree of population agglomeration and spatial development

intensity were highly concentrated in the eastern counties, such as the Beijing-Tianjin-

Hebei region, Yangtze River delta and Pearl River Delta. The area around these regions

presents moderate population concentration levels. For instance, H2 is an important part

of the Yangtze River Economic Belt, and an obvious core-periphery spatial structure

exists in the Yangtze River delta and the Chengdu-Chongqing region. However, the

structure could not be clearly captured in the urban agglomeration in the middle reaches

of the Yangtze River. Jin et al. (2018) also found that urbanization efficiency presented

a "bar-like" distribution across the Yangtze River Economic Belt and suggested a

balanced level of development within the middle and lower reaches of this economic

region. In western regions far from coastal areas, the agglomeration effect was either

373   very weak or not concentrated. The depressed economic and infrastructural conditions,

374   along with the greater employment opportunities in cities, induced mass population

375   migration from rural to urban areas (Fang et al., 2016; Li, Y. et al., 2018). This further

376   suggests that efforts for traffic improvement can potentially promote the development

377   of transportation networks (Luo and Shen, 2009).

378   In terms of governance, an extremely important aspect for nationwide

379   environmental management is the efficient implementation of rigid macro-strategic

380   targets in micro-administrative cells, which has still been a longstanding challenge in

381   China. This study offered insights into filling this gap and developed links between

382   county level management and national or provincial governance. Managers can not only

383   recognize the quality of urbanization nationwide but also can identify the problem at

384   the county level, and make timely adjustment to adapting the national intent. However,

385   the limitations of the environmental management is that this kind of assessment

386   mechanism is still not perfect yet and needs to be developed in a regular manner to

387   respond to future urban development trends in China. This study used China as a case

388   study, and it also provided insights into the achievement of sustainable urbanization that

389   could guide other developing countries. Problems caused by rapid urbanization

390   commonly exist in cities in the developing world, such as India (Ramachandra et al.,

391   2015), Brazil (De Oliveira et al., 2019) and Egypt (Abd-Elmabod et al., 2019). Although

392   the specifics will probably differ between countries and spatial scales, the demand for

393   detailed nation-scale assessments on the UDLs to support target setting are likely to be

394   common. Hence, the idea and proposed method can help comprehensively evaluate the

395   urbanization process, recognize the cause of depressed urbanization practices, and

396   inform decision-making to develop suitable strategies towards orderly urban

397   development in these countries.

398   4.2 Policy recommendations

399   To elevate the construction of the "two-horizontal" spatial urbanization pattern and

400   to improve the effectiveness of MFAP, future decision-makers should adequately

401   consider county-level differences in the UDLs of the MFAs. Policy recommendations

402   to help end the traditional "one size fits all" policies for China's urban development and

403   land space management:

404   (1) It is suggested to promote industrial and spatial optimization in the coastal

405   passageway (L1), especially in the ODAs. The Chinese government should relieve

406   stress from excessive agglomeration of the population and economy of the ODAs in the

407   Beijing-Tianjin-Hebei region, the Yangtze River delta and the Pearl River delta. It is

408   imperative that high-tech industries and advanced manufacturing bases be constructed

409   to attract labor transfers in the counties near Beijing, Shanghai and Guangzhou. To

410   strictly control the expansion of new built-up areas, demarcation of the boundaries of

411   urban development is urgently needed. A list of areas where industrial access is banned

412   is considered a feasible supplement to promote the upgrading of the industrial structure.

413   (2) Regional cooperation and linkages must be improved in the passage along the

414   Yangtze River (H2). To foster the rise of the central region, the KDAs in the middle

415   reaches of the Yangtze River in H2 still need more inter-province cooperation among

416   Hubei, Hunan and Jiangxi. Constructing a three-dimensional traffic network is

417   suggested to promote interconnected development among the urban agglomerations. It

418   is highly recommended to speed up the construction of the ports in Wuhan, Changsha,

419   Hefei and Nanchang along the Yangtze River waterway.

420   (3) Strengthen the external investment and infrastructural construction in the

421   KDAs in the western Asia-Europe land bridge (H1) and the endpoints of the "Baotou

422   to Kunming" passageway (L3). An "overall protection and local development" mode

423   should also be developed. It is imperative to improve the construction of infrastructure

424   and public service facilities in the western KDAs. Government investments in the

425   industrial development of the KDAs should focus on the processing of agricultural and

426   livestock products in the central-southern region of Tibet, energy trading with central

427   Asia in the northern hillslope area of the Tian Shan Mountains, new material processing

428   in the Lanzhou-Xining area, tourism in central Yunnan Province, etc.

429   (4) Attention should be paid to the development transformation of the old

430   northeastern industrial base in the "Beijing-Kazakhstan to Beijing-Guangzhou"

431   passageway (L2). The combination of new technologies such as big data and artificial

432   intelligence with the traditional manufacturing industry and new industries such as

433   ecological agriculture are recommended for the KDAs in the Harbin-Changchun area.

434   Economic cooperation between Northeast China and the other countries in Northeast

435   Asia and the economic corridor among China-Mongolia-Russia are also suggested.

436   **5. Conclusions**

437   In this study, a comprehensive evaluation system reflecting the UDLs reflecting

438   the UDLs throughout the 2850 county-level administrations in China was successfully

439   developed. UDLs from 2009-2015 after the implementation of MFAP was assessed.

440   The main conclusions were as follows. The UDLs in China showed a generally

441   increasing trend from 2009 to 2015. The regions in the five main urban belts presented

442   higher UDLs under the combined action of population, space and the economy. The

443   counties in the nodes of the urbanization spatial pattern, especially the ODAs and KDAs,

444   significantly contributed to urban development. However, there were obvious spatial

445   differences in the UDLs. The differences in the UDLs in the east-west direction were

446   greater than those in the north-south direction in China. The proportion of counties

447   whose UDLs ranged from Class I to Class III in the five belts and 31 provinces indicated

448   a gradual reduction in the distribution but a narrowing of the differences between the

449   east and the west. Moreover, the differences in the UDLs were linked to a spatial

450   agglomeration effect, especially in the Yangtze River Economic Belt. This was mainly

451   attributed to the effects of transportation and infrastructure. Finally, important policy

452   implications for China's further urban development and land space management were

453   inferred.

454   Overall, the implementation of MFAP has met its objectives in improving urban

455   development in China. However, regional disparities in the UDLs still need to be

456   addressed. Measures to refine management in MFAP should continue to advance to lead

457   to fundamental improvement in China's sustainable urban development. The

458   limitations of this study lie in data acquisition. Due to the availability of county-level

459   data, indicators reflecting environmental elements such as wastewater discharge

460   volume and air quality index were not included. In addition, because the publication of

461 the statistical yearbooks lags behind the current time period, an efficient data mining

462 method should be developed to reflect the dynamic changes in the UDLs in future

463 studies. The development of an information platform combining a database and

464 evaluation method is suggested for periodic assessment of urban development.

Acknowledgments

References

Abd-Elmabod, S.K., Fitch, A.C., Zhang, Z., Ali, R.R., Jones, L., 2019. Rapid urbanisation threatens fertile agricultural land and soil carbon in the Nile delta. J Environ Manage 252, 109668.

Al shawabkeh, R., Bagaeen, S., Al_Fugara, A.K., Hijazi, H., 2019. The role of land use change in developing city spatial models in Jordan: The case of the Irbid master plan (1970–2017). Alexandria Engineering Journal 58(3), 861-875.

Amiri, V., Rezaei, M., Sohrabi, N., 2014. Groundwater quality assessment using entropy weighted water quality index (EWQI) in Lenjanat, Iran. Environ. Earth Sci. 72(9), 3479-3490.

Bai, X., Chen, J., Shi, P., 2012. Landscape urbanization and economic growth in China: positive feedbacks and sustainability dilemmas. Environ Sci Technol 46(1), 132-139.

Bai, X., Shi, Peijun., Liu, Yansui, 2014. Realizing China's urban dream. Nature 509(7499), 158-160.

Bai, Y., Deng, X., Jiang, S., Zhang, Q., Wang, Z., 2018. Exploring the relationship between urbanization and urban eco-efficiency: Evidence from prefecture-level cities in China. J. Clean Prod. 195, 1487-1496.

Bren d'Amour, C., Reitsma, F., Baiocchi, G., Barthel, S., Guneralp, B., Erb, K.H., Haberl, H., Creutzig, F., Seto, K.C., 2017. Future urban land expansion and implications for global croplands. Proc Natl Acad Sci U S A 114(34), 8939-8944.

Chandra, S., Vadali, S., 2014. Evaluating accessibility impacts of the proposed America 2050 high-speed rail corridor for the Appalachian Region. J. Transp. Geogr. 37, 28-46.

Chen, M., Liu, W., Lu, D., Chen, H., Ye, C., 2018. Progress of China's new-type urbanization construction since 2014: A preliminary assessment. Cities 78, 180-193.

Chen, M., Liu, W., Tao, X., 2013. Evolution and assessment on China's urbanization 1960–2010: Under-urbanization or over-urbanization? Habitat Int. 38, 25-33.

Chen, M., Lu, D., Zha, L., 2010. The comprehensive evaluation of China's urbanization and effects on resources and environment. J. Geogr. Sci. 20(1), 17-30.

Colléony, A., Shwartz, A., 2019. Beyond Assuming Co-Benefits in Nature-Based Solutions: A Human-Centered Approach to Optimize Social and Ecological Outcomes for Advancing Sustainable Urban Planning. Sustainability 11(18), 4924.

De Oliveira, B.R., Da Costa, E.L., Carvalho-Ribeiro, S.M., Maia-Barbosa, P.M., 2019. Land use dynamics and future scenarios of the Rio Doce State Park buffer zone, Minas Gerais, Brazil. Environ Monit Assess 192(1), 39.

Dhakal, S., Imura, H., 2003. Policy-based Indicator Systems: emerging debates and lessons. Local Environment 8(1), 113-119.

Du, Q., Wang, Y., Ren, F., Zhao, Z., Liu, H., Wu, C., Li, L., Shen, Y., 2014. Measuring and Analysis of Urban Competitiveness of Chinese Provincial Capitals in 2010 under the Constraints of Major Function-Oriented Zoning Utilizing Spatial Analysis. Sustainability 6(6), 3374-3399.

Fan, J., Sun, W., Yang, Z., Fan, P., Chen, D., 2012a. Focusing on the major function-oriented zone: A new spatial planning approach and practice in China and its 12th Five-Year Plan. Asia Pac. Viewp. 53(1), 86-96.

Fan, J., Sun, W., Zhou, K., Chen, D., 2012b. Major Function Oriented Zone: New method of spatial regulation for reshaping regional development pattern in China. Chin. Geogr. Sci. 22(2), 196-209.

Fan, J., Wang, Y., Wang, C., Chen, T., Jin, F., Zhang, W., Li, L., Xu, Y., Dai, E., Tao, A., Zhou, K., Li, J., Tang, Q., Chen, D., Guo, R., 2019. Reshaping the Sustainable Geographical Pattern: A Major Function Zoning Model and Its Applications in China. Earth's Future 7(1), 25-42.

Fan, J., Zhou, k., Chen, D., 2013. Innovation and practice of economic geography for optimizing spatial development pattern in construction of ecological civilization. Econ. Geogr. 33(1), 1-8.

Fang, C., Li, G., Wang, S., 2016. Changing and Differentiated Urban Landscape in China: Spatiotemporal Patterns and Driving Forces. Environ Sci Technol 50(5), 2217-2227.

Gao, J., Wei, Y., Chen, W., Yenneti, K., 2015. Urban Land Expansion and Structural Change in the Yangtze River Delta, China. Sustainability 7(8), 10281-10307.

Gaughan, A.E., Stevens, F.R., Huang, Z., Nieves, J.J., Sorichetta, A., Lai, S., Ye, X., Linard, C., Hornby, G.M., Hay, S.I., Yu, H., Tatem, A.J., 2016. Spatiotemporal patterns of population in mainland China, 1990 to 2010. Sci Data 3, 160005.

Guan, X., Wei, H., Lu, S., Dai, Q., Su, H., 2018. Assessment on the urbanization strategy in China: Achievements, challenges and reflections. Habitat Int. 71, 97-109.

Hák, T., Janoušková, S., Moldan, B., 2016. Sustainable Development Goals: A need for relevant indicators. Ecol. Indic. 60, 565-573.

Hasan, A., Patel, S., Satterthwaite, D., 2005. How to meet the millennium development. Environ. Urban. 17(1), 3-19.

He, J., Wang, S., Liu, Y., Ma, H., Liu, Q., 2017. Examining the relationship between urbanization and the eco-environment using a coupling analysis: Case study of Shanghai, China. Ecol. Indic. 77, 185-193.

Holden, M., 2006. Urban indicators and the integrative ideals of cities. Cities 23(3), 170-183.

Klopp, J.M., Petretta, D.L., 2017. The urban sustainable development goal: Indicators, complexity and the politics of measuring cities. Cities 63, 92-97.

Kuang, W., Liu, J., Dong, J., Chi, W., Zhang, C., 2016. The rapid and massive urban and industrial land expansions in China between 1990 and 2010: A CLUD-based analysis of their trajectories, patterns, and drivers. Landsc. Urban Plan. 145, 21-33.

Li, B., Chen, D., Wu, S., Zhou, S., Wang, T., Chen, H., 2016. Spatio-temporal assessment of urbanization impacts on ecosystem services: Case study of Nanjing City, China. Ecol. Indic. 71, 416-427.

Li, G., Sun, S., Fang, C., 2018. The varying driving forces of urban expansion in China: Insights from a spatial-temporal analysis. Landsc. Urban Plan. 174, 63-77.

Li, H., Ning, Y., Wei, Y., Chen, F., 2016. SPATIAL DISTRIBUTION AND CORRELATION MECHANISM OF MEGALOPOLISES ON YANGTZE RIVER ECONOMIC BELT. Resources and Environment in the Yangtze Basin 25(12), 1797-1806 (in Chinese).

Li, J., Huang, X., Kwan, M.-P., Yang, H., Chuai, X., 2018. The effect of urbanization on carbon dioxide emissions efficiency in the Yangtze River Delta, China. J. Clean Prod. 188, 38-48.

li, L., Liu, Y., 2019. SpatialTemporal Patterns and Driving Forces of Sustainable Urbanization in China Since 2000. J. Urban Plann. Dev. 145(4), 14-18.

Li, Y., Jia, L., Wu, W., Yan, J., Liu, Y., 2018. Urbanization for rural sustainability – Rethinking China's urbanization strategy. J. Clean Prod. 178, 580-586.

Li, Y., Li, D., 2014. Assessment and forecast of Beijing and Shanghai's urban ecosystem health. Sci Total Environ 487, 154-163.

Li, Y., Li, Y., Zhou, Y., Shi, Y., Zhu, X., 2012. Investigation of a coupling model of coordination between urbanization and the environment. J Environ Manage 98, 127-133.

Li, Y., Zheng, J., Li, F., Jin, X., Xu, C., 2017. Assessment of municipal infrastructure development and its critical influencing factors in urban China: A FA and STIRPAT approach. PLoS One 12(8), e0181917.

Liu, N., Liu, C., Xia, Y., Da, B., 2018. Examining the coordination between urbanization and eco-environment using coupling and spatial analyses: A case study in China. Ecol. Indic. 93, 1163-1175.

Liu, W., Liu, J., Kuang, W., Ning, J., 2017. Examining the influence of the implementation of Major Function-oriented Zones on built-up area expansion in China. J. Geogr. Sci. 27(6), 643-660.

Liu, Y., Chen, J., He, W., Tong, Q., Li, W., 2010. Application of an Uncertainty Analysis Approach to Strategic Environmental Assessment for Urban Planning. Environ. Sci. Technol. 44, 3136-3141.

Liu, Y., Zhang, X., Kong, X., Wang, R., Chen, L., 2018. Identifying the relationship between urban land expansion and human activities in the Yangtze River Economic Belt, China. Appl. Geogr. 94, 163-177.

Liu, Z.S., Wei, H.M., 2014. Research of Shaanxi Province Urbanization Development Quality Evaluation Based on the Entropy Value Method. Applied Mechanics and Materials 587-589, 155-160 (in Chinese).

Long, H., Ge, D., Zhang, Y., Tu, S., Qu, Y., Ma, L., 2018. Changing man-land interrelations in China's farming area under urbanization and its implications for food security. J Environ Manage 209, 440-451.

Luo, X., Shen, J., 2009. A study on inter-city cooperation in the Yangtze river delta region, China. Habitat Int. 33(1), 52-62.

Mao, D., He, X., Wang, Z., Tian, Y., Xiang, H., Yu, H., Man, W., Jia, M., Ren, C., Zheng, H., 2019. Diverse policies leading to contrasting impacts on land cover and ecosystem services in Northeast China. J. Clean Prod. 240, 117961.

Medina, M.G., Huete García, M.Á., 2019. Real innovation in urban planning? Assessing the institutional capacity in the frame of the integrated sustainable urban development programmes. Eur. Plan. Stud., 1-22.

Meijering, J.V., Tobi, H., Kern, K., 2018. Defining and measuring urban sustainability in Europe: A Delphi study on identifying its most relevant components. Ecol. Indic. 90, 38-46.

Moreno Pires, S., Fidélis, T., Ramos, T.B., 2014. Measuring and comparing local sustainable development through common indicators: Constraints and achievements in practice. Cities 39, 1-9.

Ouyang, Z., Zheng, H., Xiao, Y., Polasky, S., Liu, J., Xu, W., Wang, Q., Zhang, L., Xiao, Y., Rao, E., 2016. Improvements in ecosystem services from investments in natural capital. Science 352, 1455-1459.

Parnell, S., 2016. Defining a Global Urban Development Agenda. World Development 78, 529-540.

Pleger, L.E., Lutz, P., Sager, F., 2018. Public acceptance of incentive-based spatial planning policies: A framing experiment. Land Use Pol. 73, 225-238.

Ramachandra, T.V., Bharath, A.H., Sowmyashree, M.V., 2015. Monitoring urbanization and its implications in a mega city from space: spatiotemporal patterns and its indicators. J Environ Manage 148, 67-81.

Rozhenkova, V., Allmang, S., Ly, S., Franken, D., Heymann, J., 2019. The role of comparative city policy data in assessing progress toward the urban SDG targets. Cities 95, 102357.

Shahtahmassebi, A.R., Wu, C., Blackburn, G.A., Zheng, Q., Huang, L., Shortridge, A., Shahtahmassebi, G., Jiang, R., He, S., Wang, K., Lin, Y., Clarke, K.C., Su, Y., Lin, L., Wu, J., Zheng, Q., Xu, H., Xue, X., Deng, J., Shen, Z., 2018. How do modern transportation projects impact on development of impervious surfaces via new urban area and urban intensification? Evidence from Hangzhou Bay Bridge, China. Land Use Pol. 77, 479-497.

Shen, L., Zhou, J., Skitmore, M., Xia, B., 2015. Application of a hybrid Entropy–McKinsey Matrix method in evaluating sustainable urbanization: A China case study. Cities 42, 186-194.

Shu, C., Xie, H., Jiang, J., Chen, Q., 2018. Is Urban Land Development Driven by Economic Development or Fiscal Revenue Stimuli in China? Land Use Pol. 77, 107-115.

Tan, Y., Jiao, L., Shuai, C., Shen, L., 2018. A system dynamics model for simulating urban sustainability performance: A China case study. J. Clean Prod. 199, 1107-1115.

Townsend, A., 2015. Cities of Data: Examining the New Urban Science. Public Cult. 27(2 76), 201-212.

Vojnovic, I., 2014. Urban sustainability: Research, politics, policy and practice. Cities 41, S30-S44.

Wang, J., He, T., Lin, Y., 2018. Changes in ecological, agricultural, and urban land space in 1984–2012 in China: Land policies and regional social-economical drivers. Habitat Int. 71, 1-13.

Wang, Q., Yuan, X., Zhang, J., Mu, R., Yang, H., Ma, C., 2013. Key evaluation framework for the impacts of urbanization on air environment – A case study. Ecol. Indic. 24, 266-272.

Wang, Z., Deng, X., Wong, C., Li, Z., Chen, J., 2018. Learning urban resilience from a social-economic-ecological system perspective: A case study of Beijing from 1978 to 2015. J. Clean Prod. 183, 343-357.

Wang, Z., Liang, L., Sun, Z., Wang, X., 2019. Spatiotemporal differentiation and the factors influencing urbanization and ecological environment synergistic effects within the Beijing-Tianjin-Hebei urban agglomeration. J Environ Manage 243, 227-239.

Xiao, Y., Song, Y., Wu, X., 2018. How Far Has China's Urbanization Gone? Sustainability 10(8), 2953.

Yang, W., Jiang, X., 2018. Evaluating Sustainable Urbanization of Resource-Based Cities Based on the McKinsey Matrix: Case Study in China. Journal of Urban Planning and Development 144(1), 05017020.

Yigitcanlar, T., Lönnqvist, A., 2013. Benchmarking knowledge-based urban development performance: Results from the international comparison of Helsinki. Cities 31, 357-369.

Yu, A.T.W., Wu, Y., Zheng, B., Zhang, X., Shen, L., 2014. Identifying risk factors of urban-rural conflict in urbanization: A case of China. Habitat Int. 44, 177-185.

Yu, H., Deng, Y., Xu, S., 2018. Evolutionary Pattern and Effect of Administrative Division Adjustment During Urbanization of China: Empirical Analysis on Multiple Scales. Chin. Geogr. Sci. 28(5), 758-772.

Yue, W., Wang, T., Liu, Y., Zhang, Q., Ye, X., 2019. Mismatch of morphological and functional polycentricity in Chinese cities: An evidence from land development and functional linkage. Land Use Pol. 88, 104176.

Zhan, D., Kwan, M.-P., Zhang, W., Fan, J., Yu, J., Dang, Y., 2018. Assessment and determinants of satisfaction with urban livability in China. Cities 79, 92-101.

Zhang, Q., He, K., Hong, H., 2012. Cleaning China's air. Nature 484(7393), 161-162.

Zhang, R., Jiang, G., Zhang, Q., 2019. Does urbanization always lead to rural hollowing? Assessing the spatio-temporal variations in this relationship at the county level in China 2000–2015. J. Clean Prod. 220, 9-22.

Zhang, W., Liu, Y., Feng, K., Hubacek, K., Wang, J., Liu, M., Jiang, L., Jiang, H., Liu, N., Zhang, P., Zhou, Y., Bi, J., 2018. Revealing Environmental Inequality Hidden in China's Inter-regional Trade. Environ Sci Technol 52(13), 7171-7181.

Zhang, Y., Su, Z., Li, G., Zhuo, Y., Xu, Z., 2018. Spatial-Temporal Evolution of Sustainable Urbanization Development: A Perspective of the Coupling Coordination Development Based on Population, Industry, and Built-Up Land Spatial Agglomeration. Sustainability 10(6), 1766.

Zhang, Y., Yang, Z., Yu, X., 2015. Urban Metabolism: A Review of Current Knowledge and Directions for Future Study. Environ Sci Technol 49(19), 11247-11263.

Zhao, J., Ji, G., Tian, Y., Chen, Y., Wang, Z., 2018. Environmental vulnerability assessment for mainland China based on entropy method. Ecol. Indic. 91, 410-422.

Zhao, J., Wang, M., 2018. A novel assessment of urbanization quality and its applications. Physica A: Statistical Mechanics and its Applications 508, 141-154.

Zhao, S., Zhou, D., Zhu, C., Sun, Y., Wu, W., Liu, S., 2015. Spatial and Temporal Dimensions of Urban Expansion in China. Environ Sci Technol 49(16), 9600-9609.

Zhao, Y., Leng, H., Sun, P., Yuan, Q., 2018. A Spatial Zoning Model of Municipal Administrative Areas Based on Major Function-Oriented Zones. Sustainability 10(9), 2976.

Zhou, C., Li, S., Wang, S., 2018. Examining the Impacts of Urban Form on Air Pollution in Developing Countries: A Case Study of China's Megacities. Int J Environ Res Public Health 15(8).

Zhou, D., Xu, J., Wang, L., Lin, Z., 2015. Assessing urbanization quality using structure and function analyses: A case study of the urban agglomeration around Hangzhou Bay (UAHB), China. Habitat Int. 49, 165-176.

Zou, X., Cao, G., Jiang, J., Liu, X., 2016. Assessing the Effect of the Integration among the Urbanization and Industries Development in Three Gorges Reservoir Area in China Based on P-VAR Models. J. Urban Plan. Dev 142(2), 04015015.

Zou, Z.-h., Yun, Y., Sun, J.-n., 2006. Entropy method for determination of weight of evaluating indicators in fuzzy synthetic evaluation for water quality assessment. J. Environ. Sci. 18(5), 1020-1023.
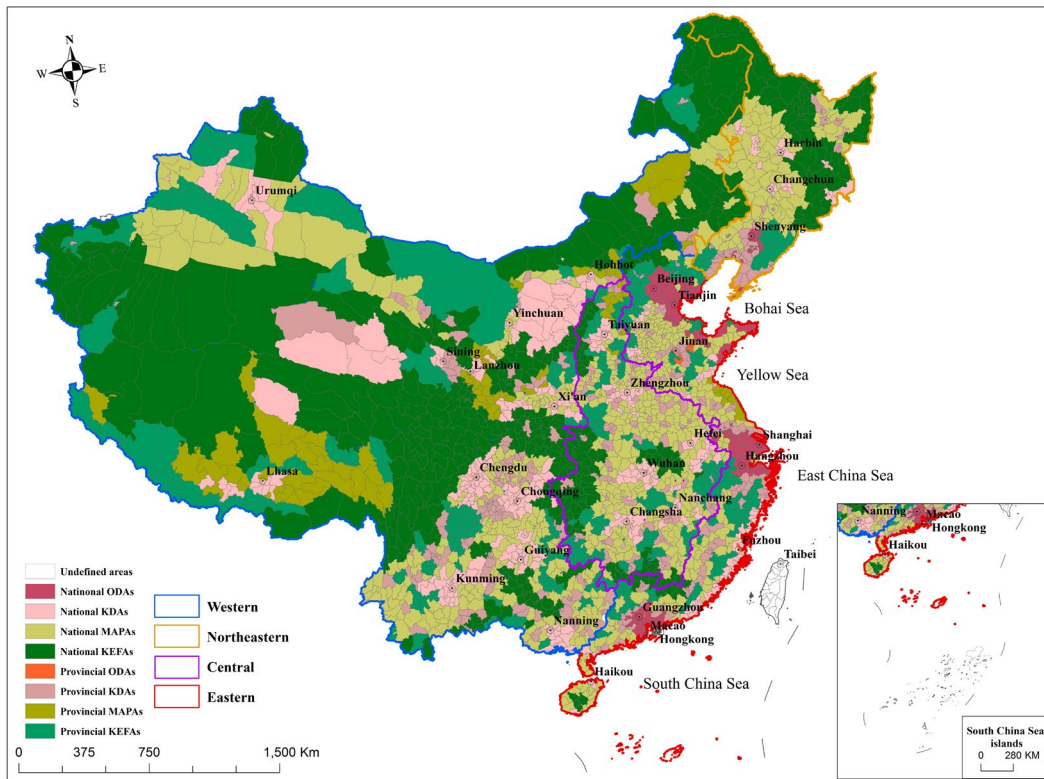
Fig.1. Main Functional Areas in China (Note: ODAs, KDAs, MAPAs, KEFAs represent Optimize development areas, Key development areas, Major agricultural production areas, and Key ecological functional areas in MFAP). *(TIFF format, 140 mm * 105 mm, 1000 dpi, 1.5 column fitting image)*
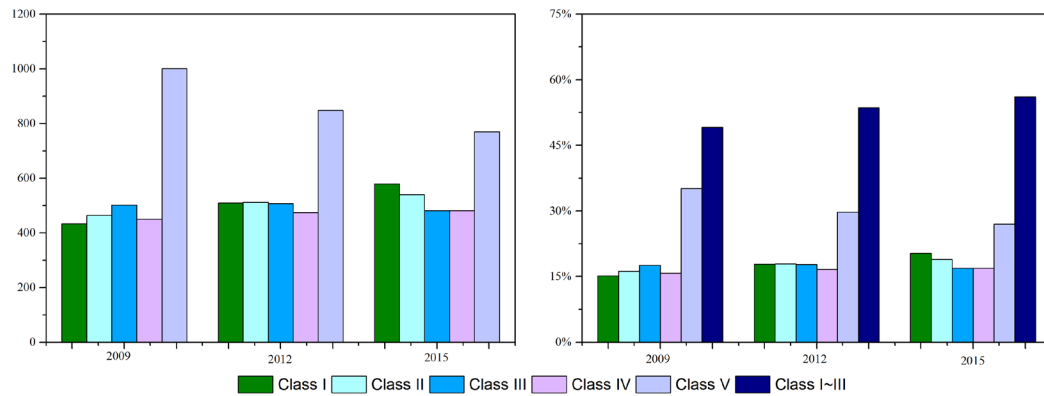

Fig. 2. UDLs from 2009 to 2015 in China. *(TIFF format, 140 mm * 54 mm, 600 dpi, 1.5 column fitting image)*
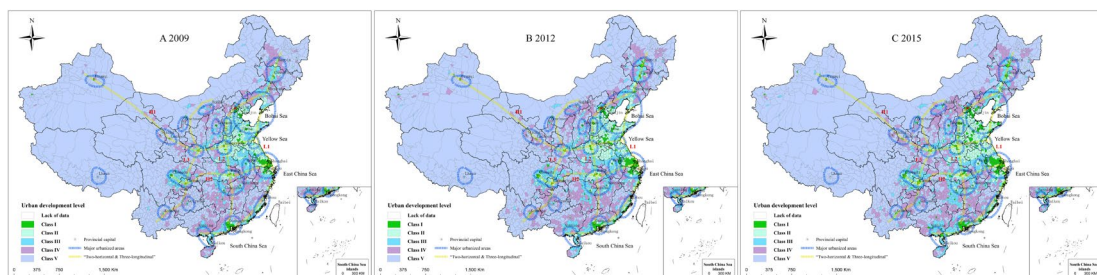
Fig. 3. Spatial distribution of UDLs from 2009-2015 in China. （Note: The notifications on the map expressed as "H1", "H2", "L1", "L2", "L3" represent the five belts in horizontal and vertical directions of the "two-horizontal and three-longitudinal" urbanization spatial pattern） *(TIFF format, 190 mm * 50 mm, 1000 dpi, 2.0 column fitting image)*
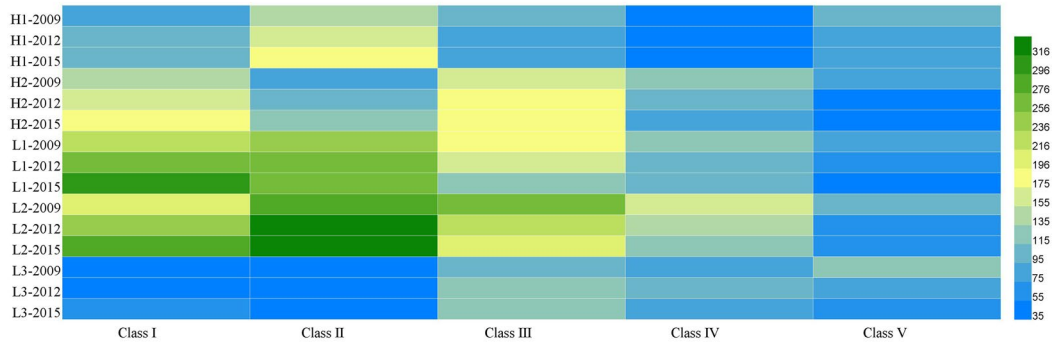

Fig. 4. Number distribution of UDLs in the spatial pattern of "two-horizontal and three-longitudinal" urbanization during 2009-2015 in China. *(TIFF format, 140 mm * 47 mm, 600 dpi, 1.5 column fitting image)*
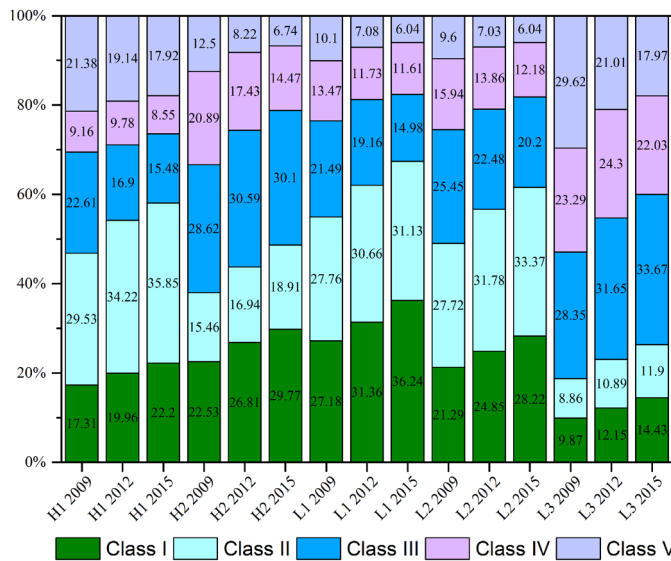

Fig. 5. Percentage distribution of UDLs in the spatial pattern of "two-horizontal" and "three-longitudinal" urbanization during 2009-2015 in China. *(TIFF format, 90 mm * 75 mm, 600 dpi, single column fitting image)*
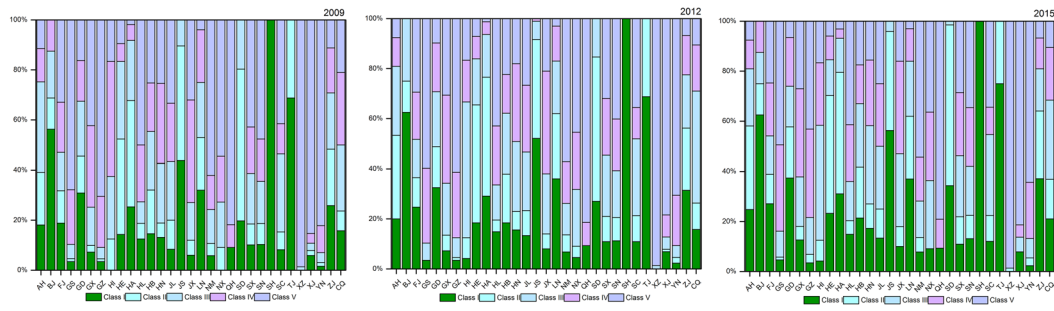
Fig. 6. Ratio variations of UDLs in the 31 provinces.

（BJ=Beijing, TJ=Tianjin, HE=Hebei, SD=Shandong, LN=Liaoning, JL=Jilin, HL=Heilongjiang, SH=Shanghai, JS=Jiangsu, ZJ=Zhejiang, FJ=Fujian, GD=Guangdong, HI=Hainan, AH=Anhui, SX=Shanxi, JX=Jiangxi, HA=Henan, HB=Hubei, HN=Hunan, GX=Guangxi, CQ=Chongqing, SC=Sichuan, GZ=Guizhou, YN=Yunnan, NM= Inner Mongolia, SN=Shaanxi, GS=Gansu, QH=Qinghai, NX=Ningxia, XJ=Xinjiang）*(TIFF format, 140 mm * 41 mm, 600 dpi, 1.5 column fitting image)*
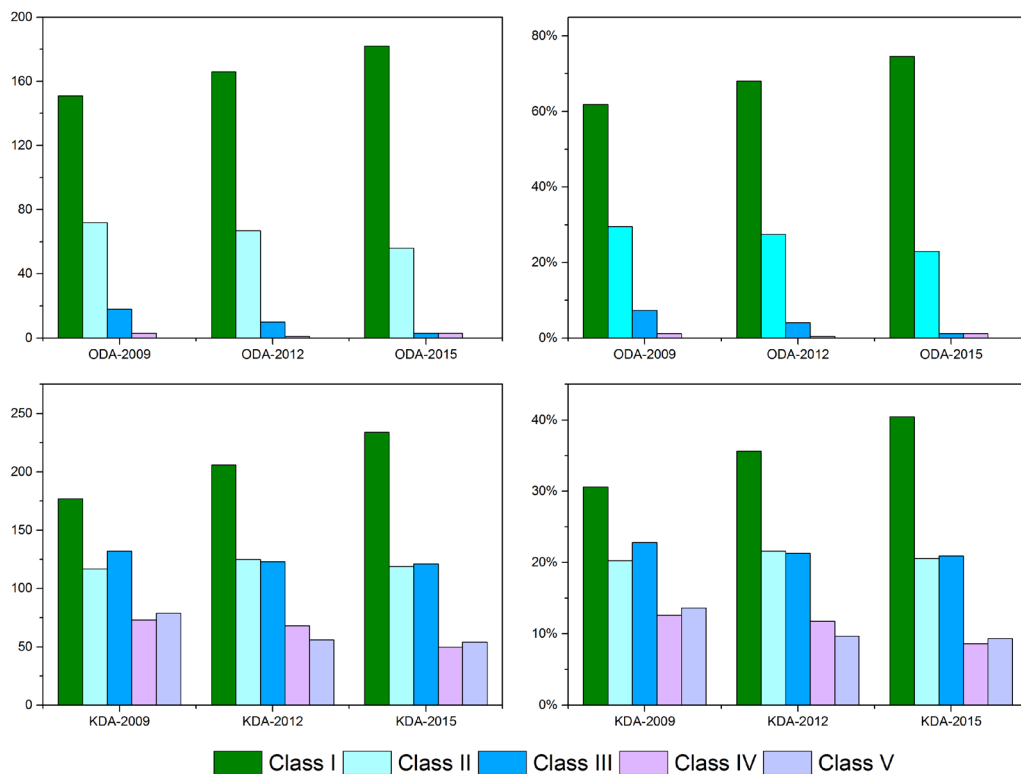

Fig. 7. Grade variations of UDLs in ODAs and KDAs. *(TIFF format, 140 mm * 105 mm, 600 dpi, 1.5 column fitting image)*

Table 1 UDLs assessment index system

First-level	Second-level	Third-level	Fourth-level
UDLs	Industrial products and services products	Land economic density	GDP (10,000 yuan) Areas of county level administrations (km^2)
	Population	Population agglomeration degree	Urban population (10,000 people) Areas of county level administrations (km^2)
	Urban space	Space development intensity	Construction land (km^2) areas of county level administrations (km^2)

Table 2 Weights of indicators

Third-level indicators	Effect direction	Weights
Land economic density	+	0.3696
Population agglomeration degree	+	0.3303
Space development intensity	+	0.3001

Note: "+" represents positive indicators. "-" represents negative indicators.

Table 3 Classification criteria for UDLs

Classification	Value of F_i	UDLs
Class I	$F_i \geq 70$	very high
Class II	$70 > F_i \geq 65$	high
Class III	$65 > F_i \geq 60$	medium
Class IV	$60 > F_i \geq 55$	low
Class V	$F_i < 55$	very low