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Research article

Spatial patterns of urban expansion and cropland loss during 2017–2022 in Guangdong, China

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ABSTRACT

Urban expansion often occurs at the expense of cropland loss, posing challenges to sustainable urban growth and food security. However, detailed investigations into urban expansion and cropland loss remain limited, particularly in regions with varying levels of urbanization. Here, we take Guangdong Province, China, as a case study to exemplify how urban expansion affects cropland using remotely sensed land use products. We adopted geospatial analysis, correlation indicators, and landscape metrics to uncover their spatial relationships at 10-m spatial resolutions. Results showed that urban areas increased by 6335 km^2 while cropland decreased by 3780 km^2 from 2017 to 2022. Notably, 41 % of newly expanded urban areas were from croplands, and 45 % of lost croplands were converted to urban areas. Western Guangdong experienced the largest extent of urban expansion and cropland loss, emerging as a hotspot region in recent years. Additionally, our analysis observed the increasing compactness of urban areas and the growing fragmentation of cropland landscapes over time. These findings shed light on the intricate dynamics between urban expansion and cropland loss in rapidly urbanizing regions, which provide valuable insights for sustainable urban development, agricultural practice, and land management in the future.

1. Introduction

Global urban land has continued expanding outward as the urban population grows [1,2]. It is almost inevitable that urban land expansion will occupy cropland around cities. Large-scale urban expansion by swallowing cropland brings environmental risks [3–6], such as soil degradation, degraded ecosystem services [7], and biodiversity loss [8]. Under this circumstance, how to reduce the impacts of urban expansion on cropland is the key to urban sustainability [9,10]. Thus, we need to assess how urban expansion has

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encroached on cropland during the past, and then summarize and transfer our experiences to cities that are about to urbanize. Although conflicts between urban expansion and cropland loss have been widely explored [1–3,9], their spatial correlations across regions with different urbanization levels are still unclear.

Previous studies evidenced that cropland is the primary source of urban expansion but with regional disparities. A global assessment reported that nearly 160,000 km^2 of cropland was occupied by urban expansion during 1992–2016, accounting for more than 45 % of the total expanded urban area [9]. It was estimated that 1.8–2.4 % of global croplands would be lost due to urban expansion by 2030, and about 80 % would occur in Asia and Africa [1]. In the Nile Delta, 746 km^2 of fertile cropland was converted to urban land during 1992–2015, and another 870 km^2 of cropland would vanish into urban areas by 2030 [11]. Different regions and countries' land resources vary greatly, so the extent of cropland occupation by urban expansion also varies. The dependence of urban expansion on cropland is higher in Europe, the Middle East, Northern Africa, and China, while it is relatively low in Oceania and Sub-Saharan Africa [2]. The cropland occupied by urban expansion in rapidly urbanized areas is more prominent.

China's rapid urbanization has consumed numerous croplands during the past three to four decades [12,13]. During 2001–2013, China's extensive urban expansion consumed 33,080 km^2 of cropland. Particularly, the area of cropland decreased by 13.30 % (1843 km^2) in the Pearl River Delta (PRD) [14]. Overall, cropland decreased in South China but increased in North China, and the barycenter of cropland shifted from North China to Northwest China during 1990–2015 [15]. The impact of urban development on cropland loss was greater than that of rural settlement expansion and industrial/transportation land expansion in China since 2000 [16]. Another indirect influence of urbanization is the abandonment of cropland because of the relatively low profits of the agricultural economy [17]. Nevertheless, these studies neglected the differences that may exist among cities of different urbanization levels.

Urban expansion not only reduces the area of cropland but also reshapes spatial patterns of cropland and other landscapes [18]. One of the changes is the fragmentation of cropland, which means dividing agricultural land into smaller, isolated, and irregularly shaped parcels [19]. Fragmentation can lead to the loss of economies of scale in agricultural production. Smaller and irregularly shaped parcels may not allow for efficient use of machinery, irrigation systems, or other agricultural inputs, leading to decreased productivity and increased costs. Numerous spatial landscape metrics were used to quantify spatial patterns and regional disparities of urban expansion and cropland loss [20,21]. However, the difference in landscape pattern change over time between urban land and cropland is still unclear.

Addressing these ubiquitous challenges, this study aims to disentangle the underlying relationship between urban expansion and cropland loss in China. Our focus is set on Guangdong Province, one of the nation's most dynamic and influential regions. Specifically, we address the following four questions. (1) What are the spatial patterns of urban expansion and cropland loss in Guangdong? (2) What is the conversion area, dependency, and contribution of urban expansion on cropland loss? (3) How does urban expansion-driven cropland loss vary across regions with different urbanization levels? (4) How do urban land and cropland landscapes change over time? An improved understanding of these issues will not only guide urban development and land management efforts in China but also inform other developing countries worldwide.

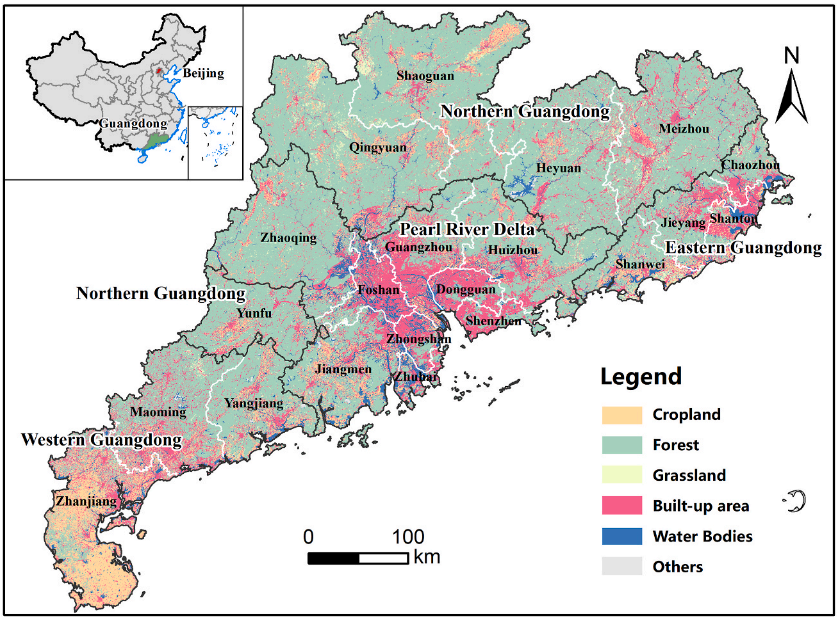

Fig. 1. Spatial distributions of land use of Guangdong Province, China, in 2022. The land use map is reclassified from the ESRI 10-m land cover product (https://livingatlas.arcgis.com/landcover/). Guangdong Province is usually divided into four regions: the Pearl River Delta, Eastern, Western, and Northern regions.

2. Study area and data

2.1. Study area

Guangdong Province is in the southernmost part of mainland China with a territorial area of nearly 180,000 km^2 (Fig. 1). By the end of 2022, Guangdong had a permanent population of 126.57 million and a GDP of 12.91 trillion RMB, with an urbanization rate of 75 %. There are 21 prefectural-level cities in Guangdong, which are typically divided into four regions: the Pearl River Delta (PRD), Eastern, Western, and Northern Guangdong (Fig. 1). The PRD is the world-class urban agglomeration, led by megacities like Guangzhou and Shenzhen. Eastern and Western Guangdong are the new growth poles, while Northern Guangdong is an ecological development zone.

2.2. Land use data

We collected land use data from the ESRI Land Cover product with a spatial resolution of 10 m (https://livingatlas.arcgis.com/landcover/). The existing artificial intelligence (AI) land classification models were enhanced by bringing together a massive training dataset of billions of human-labeled image pixels [22]. These models were applied to the entire Sentinel-2 scene collection for each year from 2017 to 2022 – that's over 2,000,000 Earth observations from 6 spectral bands to produce the maps. This land-use product has high spatial resolution and it will be updated each year, which provides the possibility for follow-up studies. This land cover product has been used in previous studies [23].

We pre-processed the ESRI land cover data for two years (2017 and 2022) of Guangdong Province, China. The original land use data for the region includes nine types: water, trees, flooded vegetation, crops, built area, bare ground, snow/ice, clouds, and rangeland. From 2017 to 2022, the proportions of the following four types (flooded vegetation, bare ground, snow, and clouds) were all below 0.4 % in the study area. Therefore, we merged them into others. Finally, we reclassified the original land use data into six categories: cropland (crops), forest (trees), grassland (rangeland), built-up areas (built area), water bodies (water), and others.

3. Methods

3.1. Hotspot analysis

We adopt *Getis Ord Gi** to identify spatial clusters of changes in built-up areas and cropland. *Getis-Ord Gi** is a local spatial autocorrelation index based on the distance weight matrix (Equation (1)) [24]:

$$Gi^{*} = \frac{\sum_{j=1}^{n} w_{i,j}x_j - \overline{X}\sum_{j=1}^{n} w_{i,j}}{S\sqrt{\frac{n\sum_{j=1}^{n} w_{i,j}^{2} - \left(\sum_{j=1}^{n} w_{i,j}\right)^{2}}{n-1}}} \tag{1}$$

where n is the total number of data points, x_j is the attribute value of point j, $\overline{X}$ is the average of all pixel values, $w_{i,j}$ is the spatial weight vectors between the point i in processing and the neighboring point j, and S is the standard deviation.

*Getis–Ord Gi** provides a *Z*-score as the resultant value. A positive Z-score indicates a hotspot and a low Z-score denotes a cold spot. The Z-score represents the statistical significance of clustering for a specified distance (90 % significant: $>$1.65 or $<$ -1.65; 95 % significant: $>$1.96 or $<$ -1.96; 99 % significant: $>$2.58 or $<$ -2.58). This study identified the hot spots of increased/decreased built-up areas and cropland during 2017–2022 using *Getis-Ord Gi** in *ArcGIS* 10.7.

3.2. Land-use transfer matrix

We adopted a land-use transfer matrix to quantify land use changes during 2017–2022 in Guangdong. The land-use transfer matrix is a two-dimensional matrix revealing the interconversion between different types of land use at two-time points. It can reflect not only the areas of land use change but also the transfer out of each type of land use at the beginning and the transfer in of each type at the end. Usually, the land-use transfer matrix rows indicate the land use type at a former time, and the columns indicate the land use information at a later time.

3.3. Dependence and contribution metrics

We adopted two indices to build correlations between urban expansion and cropland loss, which are the dependence of urban expansion on cropland (DEP) and the contribution of cropland to urban expansion (CON), respectively [12]:

$$DEP = \frac{ACU}{AU} \times 100\% \tag{2}$$

$$CON = \frac{ACU}{AC} \times 100\% \tag{3}$$

where *ACU* is the cropland area occupied by urban expansion, *AU* is the total area of newly expanded built-up areas, and *AC* is the total cropland converted to other types of land use.

The value of *DEP* and *CON* ranges from 0 to 1. The higher the *DEP* value, the higher the dependence of urban expansion on cropland. If *DEP* equals 1, all newly expanded built-up areas are derived from cropland. Similarly, the higher the *CON* value, the more significant the contribution of lost cropland to urban expansion. When $CON = 1$, all the loss of cropland is transformed into built-up areas.

3.4. Landscape analysis

We selected three landscape metrics to quantify landscape patterns of built-up areas and cropland (Table 1). *PLAND* is the proportion of various types of land in the total area. Patch density (*PD*) reflects the spatial distribution density of patches. Under the same landscape area, the higher the patch density, the higher the fragmentation degree. The clustering index (*AWMSI*) indicates the spatial connectivity of patches. The larger the clustering index, the more concentrated the spatial distribution of patches and the closer the connection.

We selected four cities in the four regions of Guangdong Province, which represent different stages of development (Fig. 2). *Guangzhou-Foshan* was chosen for the Pearl River Delta region, and these two cities are regarded as urban complexes (Fig. 2a). *Maoming*, *Shaoguan*, and *Shantou* are chosen to represent Western, Northern, and Eastern Guangdong, respectively. We built concentric rings to analyze landscape changes in built-up areas and cropland [25]. The location of the municipal government is defined as the center of the concentric rings. For *Guangzhou-Foshan*, the buffer interval was set as 2 km with 20 rings. For *Maoming* (Fig. 2b) and *Shaoguan* (Fig. 2c), we built 20 buffer zones with a 1-km interval. For *Shantou*, we built 20 buffer zones with a 0.5-km interval (Fig. 2d).

4. Results

4.1. Spatial changes of built-up areas and cropland

We used *Getis-Ord Gi** (Equation (1)) and high-low clustering tools to determine the spatial pattern of increased/decreased built-up areas and cropland (Fig. 3). The increased built-up areas are mainly clustered in three areas: *Maoming-Zhanjiang*, an urban agglomeration dominated by *Guangzhou* and *Foshan*, and the eastern part of Guangdong (Fig. 3a). In contrast, the agglomeration pattern of newly added built-up areas in northern Guangdong Province is insignificant. The spatial distribution of the reduced built-up areas is more random and less clustered than the other three (Fig. 3b).

The increased/decreased cropland showed different patterns (Fig. 3c and d). Changes in cropland mainly occurred in Western Guangdong, especially in *Zhanjiang*, *Maoming*, *Yangjiang,* and *Jiangmen.* In these four cities, the increased and decreased cropland show evident clustering, mainly because most of Guangdong's cropland is distributed in this area. In *Meizhou*, *Chaozhou*, *Jieyang*, *Yunfu*, *Huizhou,* and *Zhaoqing*, the loss of cropland is more prominent. Among cities in Northern Guangdong, *Shaoguan* has seen a more significant increase in cropland. Policy support and improvements in agricultural infrastructure have helped *Shaoguan* become the granary of Guangdong, with more high-standard cropland being built in recent years. This makes *Shaoguan* present a completely different situation from other cities. In addition, the increased built-up areas and decreased cropland showed a similar spatial distribution (Fig. 3a and d). This means that most of the lost cropland was converted into urban land between 2017 and 2022.

In terms of regional disparity, changes in built-up areas and cropland varied across 21 prefecture-level cities during 2017–2022 (Fig. 4). *Shenzhen* experienced the least increment of built-up areas at 74 km^2. The PRD region was already highly urbanized, and urban expansion was slowing down, while other cities surrounding the PRD were still in rapid urban expansion. *Maoming* and *Zhanjiang* have more than 750 km^2 of newly added built-up areas (Fig. 4a). In terms of cropland, the compensation could not meet the requisition, resulting in a net decrease in cropland (Fig. 4b). *Zhanjiang* experienced the largest decrease in cropland by more than 1000 km^2 while only 618 km^2 cropland was newly added. *Maoming*, *Jiangmen,* and *Shaoguan* reduced their cropland by more than 490 km^2 but added less cropland than they lost.

Moreover, we conducted a correlation analysis to examine the relationship between changes in built-up areas and cropland from 2017 to 2022. The results revealed a strongly correlated negative relationship at both the county level (adjusted $R^2 = 0.79$) and the district level (adjusted $R^2 = 0.73$) (Fig. 5). The slopes at the two levels are similar (-0.549 and -0.649), which means that an increase of 100 km^2 of built-up areas is usually accompanied by a loss of cropland by around 60 km^2, although not all these lost croplands were converted to built-up areas. Fig. 5 also shows the extent of urban expansion across cities. Generally, Western Guangdong experienced more urban land expansion than Eastern and Northern Guangdong. *Maoming* and *Zhanjiang*, located in Western Guangdong,

Table 1
Detailed explanations of landscape metrics.

Metrics	Abbreviation	Formula	Description
Percentage of Landscape	*PLAND*	$\frac{\sum_{j=1}^{n} a_{ij}}{A} \times 100$	a_{ij} represents the area of the *j*th patch in the *i*th landscape type; *A* is the total area of the landscape.
Patch density	*PD*	$\frac{NP}{A}$	*NP* represents the number of patches; *A* is the total area of the landscape.
Area-weighted mean shape index	*AWMSI*	$\frac{\sum (A * SI)}{TA}$	*A* represents the patch area, *SI* represents the shape index, and *TA* represents the total landscape area.

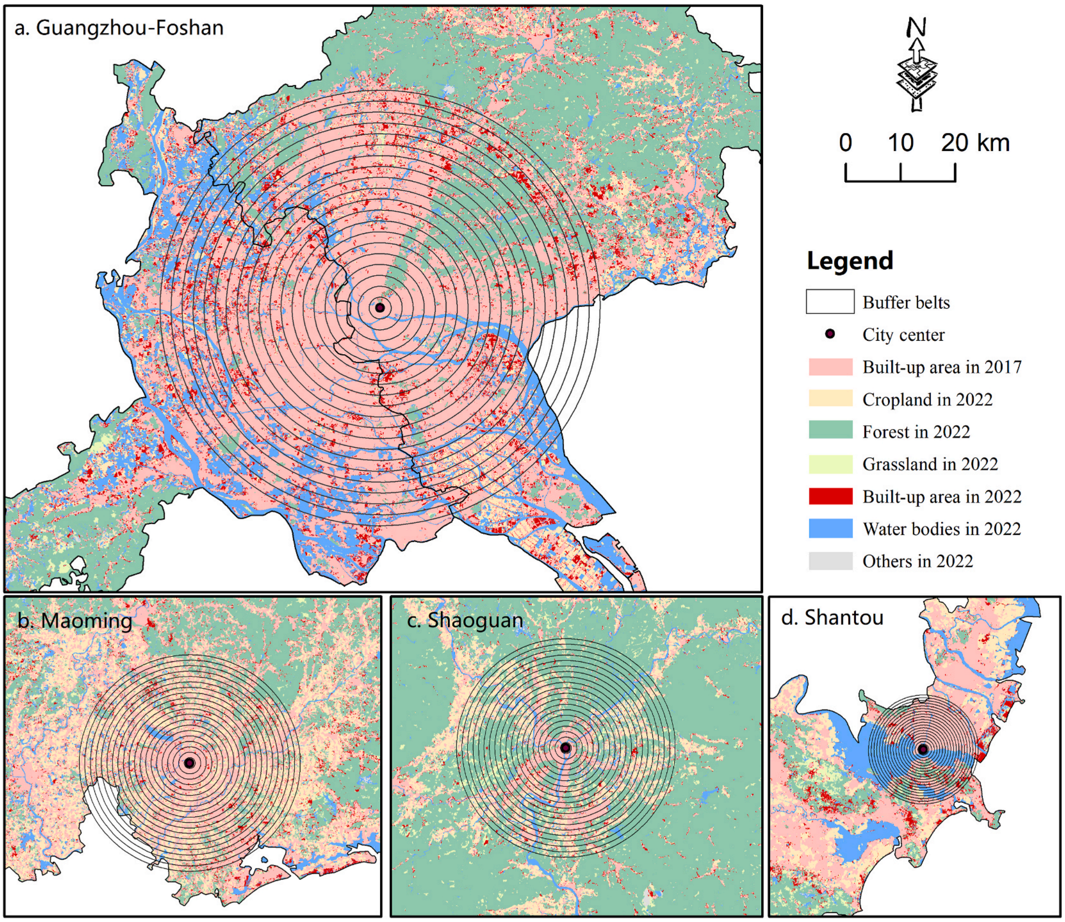

Fig. 2. Concentric ring analysis of four representative cities. (**a**) *Guangzhou-Foshan*. (**b**) *Maoming*. (**c**) *Shaoguan*. (**d**) *Shantou*.

experienced the most significant increase in built-up areas, over 600 km^2, while they also lost the most cropland during 2017–2022 (Fig. 5a). There were limited increases in built-up areas in *Shenzhen* and *Dongguan* because they are highly urbanized.

4.2. Land use conversions between urban and cropland areas

Between 2017 and 2022, Guangdong experienced an overall increase in built-up areas alongside a decrease in cropland (Table 2). On the one side, the total built-up area expanded from 26378 km^2 to 32713 km^2, with a net increase of 6335 km^2 (24.02 %). The proportion of built-up areas to the whole territorial land rose from 14.7 % in 2017 to 18.3 % in 2022. The newly expanded built-up area is 7635 km^2, among which 3112 km^2 is from cropland. On the other side, during 2017–2022, cropland areas transformed into other land amounted to 6811 km^2, with 3112 km^2 being converted to built-up areas. The area of newly added cropland is 3030 km^2. More than half of the added cropland came from forests. Even so, there was a net decrease of 3780 km^2 cropland in Guangdong from 2017 to 2022.

Spatially, the eastern part of Guangdong Province has lost the least amount of cropland and increased the least amount of new built-up area (Table 3). The Pearl River Delta region has the largest number of cities and has lost up to 1248 km^2 of cropland. From an urban perspective (Table 4), the cities with the greatest loss of cropland and the greatest increase in built-up area are in the western part of Guangdong Province. Shenzhen's loss of cropland is the smallest of all cities, with a loss of only 11 km^2, while at the same time expanding only 38 km^2 of built-up area.

4.3. Contributions of cropland to urban expansion

Through analysis of the land use transfer matrix (Table 2), it can be calculated that the general dependence of urban expansion (*DEP*, Equation (2)) on cropland is 41 % while the general contribution of cropland to urban expansion (*CON*, Equation (3)) is 45 %. At the city level, *DEP* varies from 11.68 % (*Shenzhen*) to 56.82 % (*Zhanjiang*), with an average of 38 %, which means that 38 % of newly built-up areas come from cropland. In addition, *CON* varies from 27.83 % (*Shanwei*) to 65.94 % (*Shantou*), with an average of 48.85 %, which means that 48 % of lost cropland was transformed into built-up areas. Three cities, *Zhanjiang*, *Jiangmen*, and *Huizhou*, rely on the

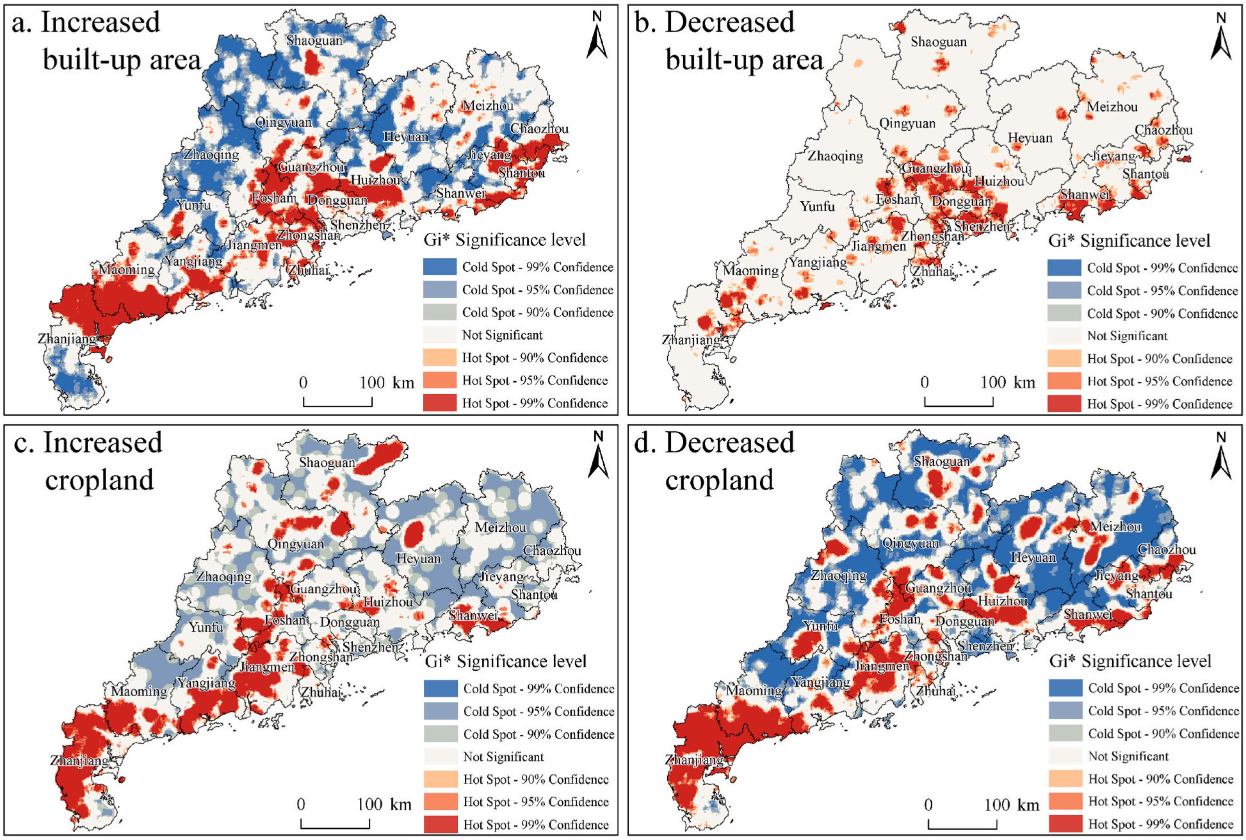

Fig. 3. Spatial patterns of hot and cold spots of increased built-up area (**a**), decreased built-up area (**b**), increased cropland (**c**), and decreased cropland (**d**) during 2017–2022 in Guangdong Province. The increased/decreased built-up areas and cropland were calculated in 1 km grids.

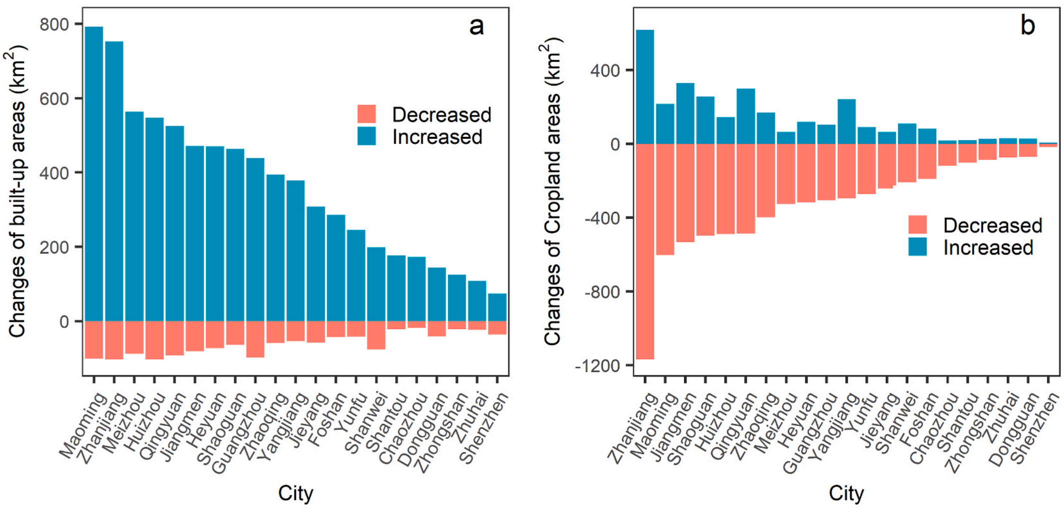

Fig. 4. Changes of built-up areas (a) and cropland (b) during 2017–2022 in 21 cities in Guangdong province, China.

loss of cropland for their expansion by more than 49 % (Fig. 6a). This shows that urban land expansion occupies not only cropland but also other lands. Nine cities have a *CON* of more than 50 %, which indicates that cropland is mainly converted to built-up areas from the perspective of cropland loss. (Fig. 6b).

We further investigate the spatial pattern of *DEP* and *CON* at the county/district level, shown in Fig. 7. Both *DEP* and *CON* present apparent spatial heterogeneities and clusters. *DEP* varies from 0 to 75.37 %. Counties/districts with high DEP values (>50 %) are

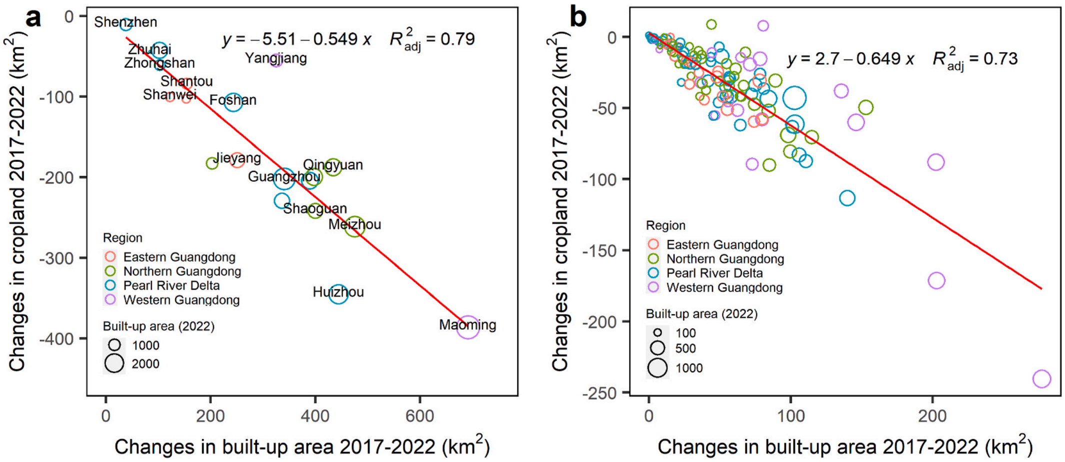

Fig. 5. Correlations between built-up areas and cropland changes at the prefectural-level city (**a**) and county/district level (**b**) during 2017–2022 in Guangdong Province, China.

Table 2
Transfer matrix for land use changes during 2017–2022 in Guangdong, China (km^2).

2017	2022						
	Cropland	Forest	Grassland	Built-up area	Water Bodies	Others	Total in 2017
Cropland	**14448**[a]	2195	1041	3112	441	22	21259
Forest	1720	**103056**	2925	2656	230	60	110647
Grassland	479	3430	**3114**	834	64	22	7943
Built-up area	371	559	187	**25078**	136	47	26378
Water Bodies	412	259	110	748	**9455**	104	11088
Others	48	195	105	285	120	**465**	1218
Total in 2022	17478	109693	7482	32713	10447	721	178534

[a] Numbers indicate areas of land use transformation in the first column to other types in the rows. Numbers in bold indicate areas of unchanged land use during 2017–2022.

Table 3
Land use changes in four regions during 2017–2022 in Guangdong, China (km^2).

Region	Cropland loss	Cropland changes	Increase in built-up area	Conversion of cropland to built-up area
PRD	1248	−22.50 %	2081	974
Western	992	−11.26 %	1666	787
Northern	1074	−20.49 %	1909	720
Eastern	466	−28.15 %	681	260

concentrated in *Jiangmen*, *Huizhou*, *Zhanjiang*, and *Shaoguan*. The spatial clusters of *CON* are more apparent. Counties/districts with high *CON* values are concentrated in the PRD region and Eastern Guangdong (Fig. 7b), indicating that most of the cropland lost (>70 %) in these regions is converted into urban land.

4.4. Spatio-temporal variations of landscapes

Urban expansion and cropland loss in space are revealed by landscape metrics (Fig. 8). In terms of temporal variations, PLAND and AWMSI of built-up areas showed an increasing trend. In contrast, PD of built-up areas decreased slightly over time (except for *Shaoguan*) (Fig. 8a). These changes indicate an increase in the proportion of built-up areas but a decrease in fragmentation, accompanied by an increase in shape complexity. From the spatial perspective, the proportion (PLAND) of built-up areas gradually decreases from the city center outward, while the fragmentation (PD) of built-up areas increases with distance from the center. For inter-city comparisons, landscape changes in the built-up area of *Shaoguan* in Northern Guangdong are more obvious than in the other three cities.

Landscape metrics for cropland are shown in Fig. 8b. *PLAND* and *AWMSI* of cropland in the same concentric ring generally showed a decreasing trend from 2017 to 2022. The fragmentation (PD) of cropland in *Guangzhou-Foshan* and *Shantou* decreased over time. From the perspective of space, the fragmentation of cropland increases first and then decreases with the distance from the center,

Table 4
Land use changes in each city during 2017–2022 in Guangdong, China (km^2).

City	Region	Cropland loss	Cropland changes	Increase in built-up area	Conversion of cropland to built-up area
Guangzhou	PRD	202	−28.01 %	341	173
Shenzhen	PRD	11	−40.37 %	38	6
Zhuhai	PRD	45	−25.44 %	84	27
Foshan	PRD	107	−31.97 %	243	105
Jiangmen	PRD	204	−11.40 %	390	201
Zhaoqing	PRD	229	−22.84 %	336	141
Huizhou	PRD	345	−28.68 %	444	239
Dongguan	PRD	43	−38.25 %	103	36
Zhongshan	PRD	61	−35.37 %	103	47
Zhanjiang	Western	551	−8.50 %	649	375
Maoming	Western	386	−29.55 %	692	304
Yangjiang	Western	55	−5.36 %	325	108
Shaoguan	Northern	242	−14.14 %	400	183
Meizhou	Northern	262	−45.83 %	475	140
Heyuan	Northern	200	−32.66 %	397	129
Qingyuan	Northern	188	−11.56 %	434	170
Yunfu	Northern	183	−25.34 %	203	98
Shantou	Eastern	84	−27.74 %	155	63
Shanwei	Eastern	100	−15.60 %	122	37
Chaozhou	Eastern	103	−51.70 %	153	63
Jieyang	Eastern	179	−35.04 %	251	97

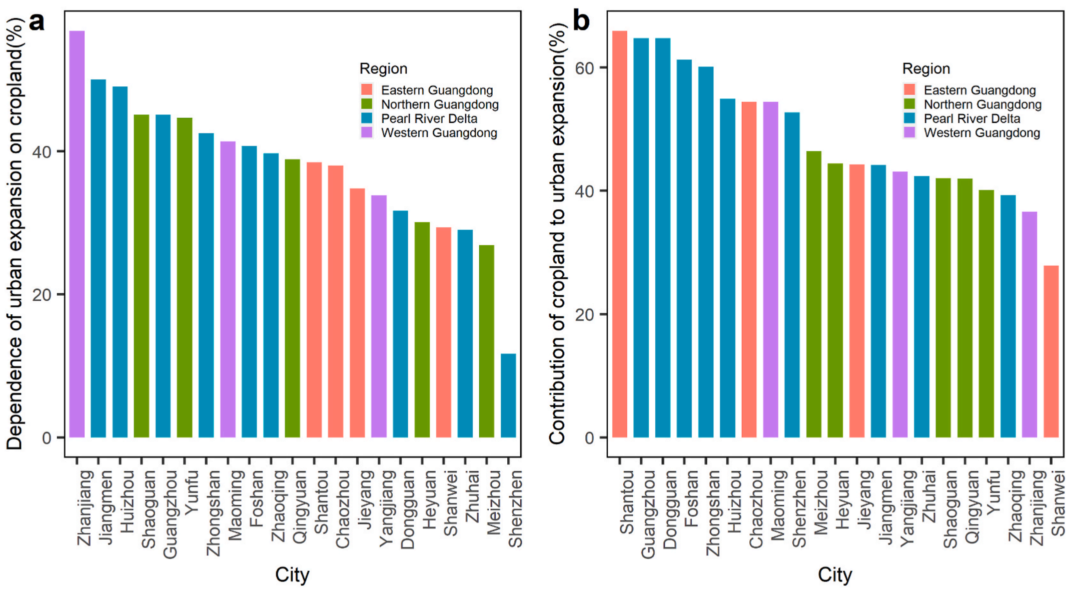

Fig. 6. Bar plots of dependence of urban expansion on cropland (**a**) and contribution of cropland to urban expansion (**b**) during 2017–2022 in 21 cities in Guangdong Province, China.

where the highest fragmentation of cropland probably experiences the highest intensity of urban land expansion. As illustrated in Fig. 9, significant fragmentation of cropland has been observed in some peri-urban regions during 2017–2022.

5. Discussion

This study quantified spatial patterns and correlations of urban expansion and cropland loss in Guangdong, a highly urbanized province in China. The net increase in built-up areas is 6335 km^2, and cropland decreased by 3780 km^2 from 2017 to 2022. Generally, 41 % of the newly built-up areas came from cropland, and 45 % of the lost cropland was converted to built-up areas, similar to a global assessment [9]. All cities have experienced urban expansion and cropland loss, with more significant changes in the cities of western Guangdong, particularly in *Maoming* and *Zhanjiang*. Using spatial analysis, we identified hotspots of increased/decreased built-up areas and cropland (Fig. 4). Urban expansion and cropland loss are highly correlated, and 60 km^2 of cropland would be lost for every 100 km^2 increase in urban land (Fig. 5). The contribution of cropland to urban expansion is relatively high and clustered in the PRD region and Eastern Guangdong (Figs. 6 and 7), where the cropland quality is relatively high.

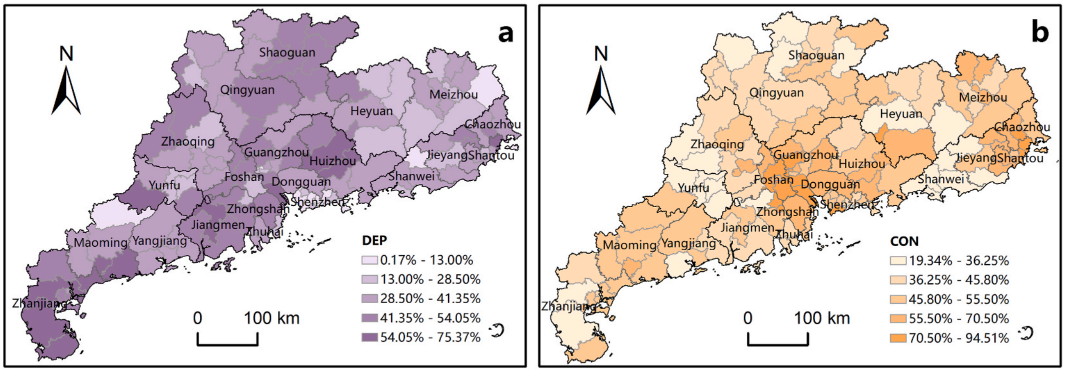

Fig. 7. Spatial distributions of dependence (*DEP*) of urban expansion on cropland (**a**) and contribution (*CON*) of cropland to urban expansion (**b**) at the county/district level during 2017–2022 in Guangdong Province, China.

The pattern of urban expansion has undergone notable shifts in Guangdong. Between 2017 and 2022, rapid urban development took place in Western and Northern Guangdong, which is different from the past three to four decades with the high speed of urban development in the PRD. For instance, from 1979 to 2009, the share of built-up area in the PRD region increased from 0.5 % to 10.8 % [26]; during the 33 years from 1987 to 2020, the built-up area of *Dongguan* increased by 13.84 times [27]. However, only 103 km^2 of new built-up area was added in *Dongguan* and 38 km^2 in *Shenzhen* from 2017 to 2022. During the past five years (2017–2022), *Maoming*, *Zhanjiang* in Western Guangdong, and *Meizhou*, *Qingyuan* in Northern Guangdong have had a significantly faster urban expansion rate from 2017 to 2022. These cities experiencing rapid urban expansion are hotspots for cropland protection. In addition, urban expansion exacerbates the spatial fragmentation and irregular distribution of cropland [28].

Urban land inevitably occupies cropland as the city grows. Cropland protection policies can help improve urban land use efficiency by restricting the diversion of cropland, keeping the total cropland area unchanged, and promoting compact urban growth. To make up for the loss of cropland occupied by urban expansion, China has instituted a land management policy known as the “requisition-compensation balance” of cropland to ensure that the total amount of cropland does not decrease [29,30]. This policy can be used as a reference for other countries to protect cropland, particularly for populous but land-scarce countries and regions. However, strict cropland protection policies may interfere with the natural development of cities and weaken the social and economic links between urban construction sites, thus reducing land use efficiency [31]. Therefore, controlling the speed and scope of urban expansion and rationally demarcating the boundaries between built-up areas and cropland is the key to realizing the sustainable use of land resources [32].

The transformation of cropland to urban land is driven by multiple factors, including physical geography, socio-economic status, land use policy settings, etc. [33,34]. Physically, cropland is generally flatter than other types of non-urban land, thus it is more suitable for urban development. Particularly, peri-urban cropland is more vulnerable because of high accessibility [35]. Urban population growth and economic development are believed as the two core factors that drive urban expansion, which are closely related to cropland loss [36]. Land use and urban planning policies also affect the conversion of cropland. In addition, different urbanization modes cause varying impacts on cropland changes [37,38].

Further studies could explore how to reduce cropland loss caused by urban expansion. It is proved that large cities reduce the cropland loss at the per capita level while accommodating the exact size of the population compared to many small cities [10]. Urban land expansion in small towns and rural settlements may occupy high-quality cropland because of high accessibility. On the other hand, rural settlements abandoned should be reclaimed for farming. It is projected that 5.8 million hectares of rural land could be released for agriculture by 2050 in China, equivalent to about 4.1 % of the total cropland in 2015 [39]. Urban expansion and cropland loss are complex processes determined by socioeconomic, physical geography, and policy-related factors. Land and agricultural policy should be combined to reduce the impacts of urban expansion on cropland.

This study acknowledges certain limitations. While we quantified the spatial patterns and correlations between urban expansion and cropland loss, further investigation into the underlying driving forces behind these changes, including macro factors (such as economic and demographical shifts) and micro influences (such as distance to road networks), is highly warranted. For instance, the Land Expansion Analysis Strategy (LEAS) module in the PLUS model offers a framework for exploring driving factors behind land use changes [40]. In addition, the study period of this research is restricted to 2017–2022 due to the availability of high-resolution land-use products. An extended examination of the interaction between urban expansion and cropland loss is anticipated in future research endeavors.

6. Conclusions

Rapid urbanization in China in recent years has presented a significant threat to existing croplands, yet there still lacks a detailed examination of them in regions with different urbanization levels. Using geospatial analysis, correlation indicators, and landscape metrics, this study contributes to the fine-scale spatial relationships between urban expansion and cropland loss in Guangdong

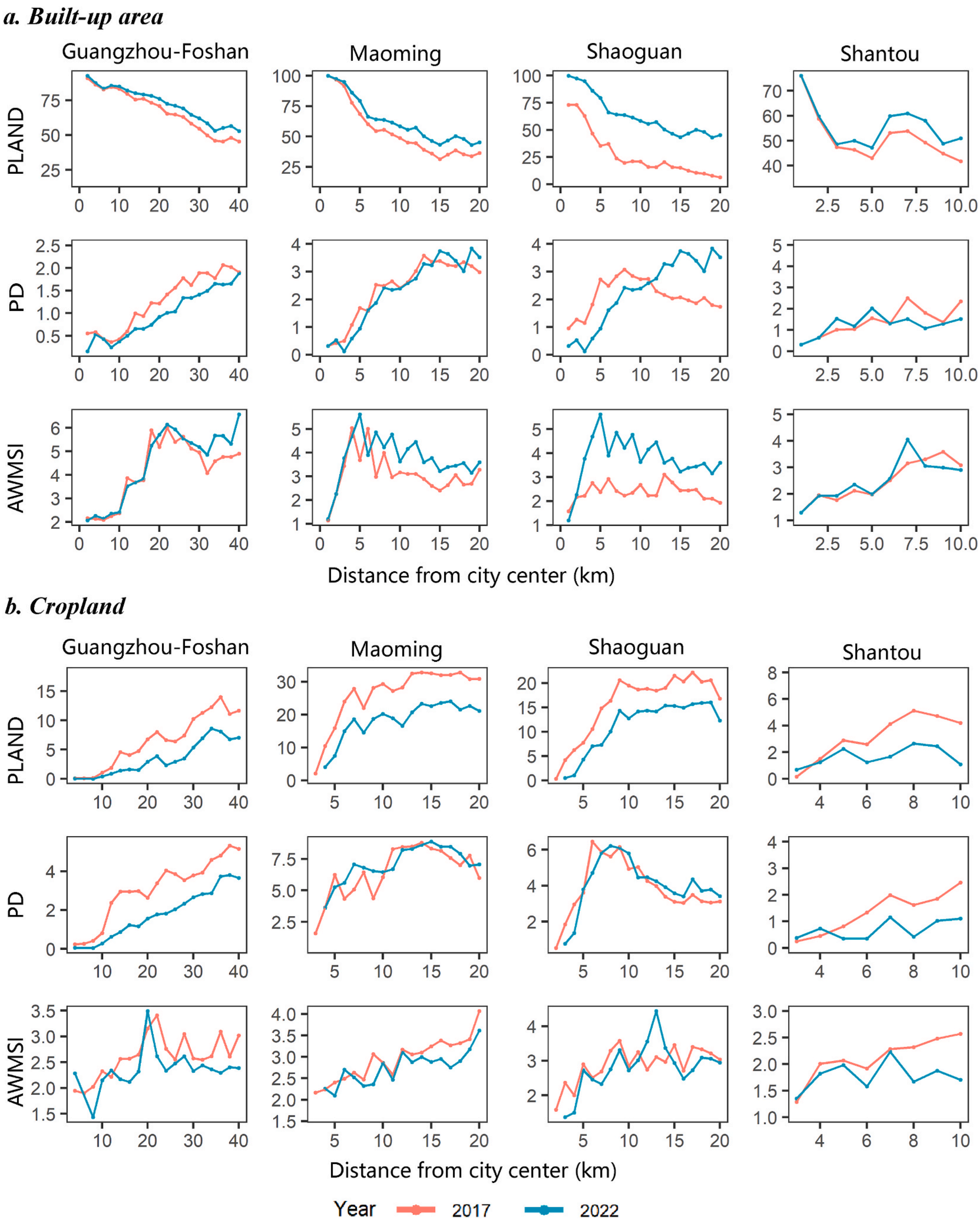

Fig. 8. Spatial gradients of landscape metrics of built-up area (a) and cropland (b) in four cities in 2017 and 2022.

Province, China. Results revealed that urban areas increased by 6335 km^2 while cropland decreased by 3780 km^2 during 2017–2022. Urban expansion exhibited a strong correlation with cropland loss, with 41 % of newly urban areas originating from cropland and 45 % of lost cropland converted to urban areas. Western Guangdong emerged as a hotspot for urban expansion and cropland loss, experiencing the most significant changes in recent years. Moreover, landscape analysis demonstrated an escalating compactness of urban areas and an increasing fragmentation of croplands over the period. To better guide sustainable land management and urban development, future research could focus on analyzing the driving forces behind these changes.

Data availability statement

Data used in this study is publicly available (https://livingatlas.arcgis.com/landcover/).

Fig. 9. Examples of cropland fragmentation in Guangdong between 2017 and 2022. (a–b) Panyu District, Guangzhou. (c–d). Dianbai District, Maoming. (e–d). Chenghai District, Shaoguan.

CRediT authorship contribution statement

Xinjian Wen: Writing – original draft, Conceptualization. **Fuying Yang:** Writing – original draft, Formal analysis, Data curation. **Jiangping Chen:** Writing – review & editing, Funding acquisition, Conceptualization. **Ying Tu:** Writing – review & editing, Methodology. **Haiyun Wang:** Methodology, Data curation. **Zhanpeng Chen:** Methodology, Data curation. **Ting Dong:** Writing – review & editing. **Gang Xu:** Writing – review & editing, Supervision, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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