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BANGKOK'S URBAN SPRAWL: LAND FRAGMENTATION AND CHANGES OF PERI-URBAN VEGETABLE PRODUCTION AREAS IN THAWI WATTHANA DISTRICT

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Abstract: Agricultural lands are heavily affected by urban sprawl. Urbanization therefore plays a significant role in changing megacities' agricultural fringes such as in Bangkok's peri-urban vegetable production areas. This study focuses on the prime vegetable production areas in Bangkok and aims to: 1) understand and determine the land use changes to these areas, 2) clarify the landscape configurations of these areas to assess landscape fragmentation, 3) discuss and recommend land use planning policies and measures to conserve the existing peri-urban agricultural landscape. We use a geographic information system (GIS) database and three thematic map layers (land use, waterways, and roads) to analyze and clarify land use proportions, changes in the vegetable production areas, and the land configurations during different periods from 1976 to 2015. The fragmentation of the vegetable production matrix increased due to the immediate effect of the expanded road network construction and due to a later consequence of the contiguous roadside urban development. The remaining vegetable production areas were mostly away from the primary road leading to the Bangkok centre city. The monitoring system on the fragmentation of agricultural lands is essential as a database to find suitable measures to control urban sprawl in various cities.

Keywords:

peri-urban agriculture;
land use changes;
urban sprawl;
vegetable production areas;
Bangkok

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Introduction

Urban sprawl is a global phenomenon that has widely occurred in a large number of cities around the world. This kind of urbanization has transformed the surrounding agricultural lands over the fringe of megacities. Agricultural lands are usually located around most of the cities because they are essential as the primary economic organ that brought about agriculture (Jacobs 1970). Von Thünen (1998) has identified the locations of several types of surrounded agricultural lands through their ability to transport products to the city. As a kind of market gardening products in the model, vegetables were usually cultivated close to towns. However, these agricultural lands were lately fragmented and changed by urban sprawl, which is characterized as scattered, leapfrog, unlimited, and unplanned urban expansion toward surrounding agricultural areas (Ocampo 1995, Gillham 2002, Burchell et al. 2005). Accordingly, several theories have been introduced as tools to limit and control urban sprawl with the idea to separate the urban from rural areas, i.e., greenbelt, smart growth, and zoning (Gillham 2002).

Bangkok, one of the fast-growing megacities in Southeast Asia, has been expanding beyond control (Kaothien 1995, McGee 1995, Robinson 1995, Vagneron 2007, McKinsey Global Institute 2018). Encroachment due to urban sprawl into prime agricultural land located around cities is a global phenomenon that also occurred in Bangkok (Mekvichai et al. 1990, Hara et al. 2005, Murakami et al. 2005, Hara et al. 2008, Hirsch 2009). Since the 1980s, the rapid economic growth and population increase in Bangkok has influenced urbanization, which has spread into the high-quality surrounding peri-urban agricultural land (Jones 1997, Yokohari et al. 2000). Peri-urban agricultural land conditions have deteriorated, and the available area has been reduced, and these factors have affected both the quality and quantity of production usually consumed by urban people (Hung and Yasuoka 2000, Sajor and Ongsakul 2007).

Vegetable production is an important integral part of Bangkok's peri-urban agriculture, which includes the other three significant crops: rice, fruits, and ornamental plants (Bangkok Agriculture Office 2018). Thawi Watthana district, located in west Bangkok (Figure 1), has been the largest vegetable production area in Bangkok (Bangkok Agriculture Office 2018). It comprises two sub-districts: Sala Thammasop and Thawi Watthana (Figure 2). People who reside in this area are a combination of the local farmers and new urban residents. The local farmers mostly live and work on the vegetable production areas while the new urban residents primarily live in the housing estates in the form of gated communities and work in the center city of Bangkok. Currently, there are 55,554 registered residents in the Sala Thammasop sub-district and 23,098 in Thawi Watthana sub-district (Thawiwatthana District Office 2020). The agricultural census in 2017 revealed that more than half of the vegetable production areas in Bangkok were in the whole Thawi Watthana district

(Bangkok Agriculture Office 2018). Therefore, the district's vegetable production areas play an essential role in providing large amounts of fresh vegetables to Bangkok urban consumers. The proximity to the city offers the advantages of short and rapid delivery, resulting in fresh and "low-miles" food products (Giradet 2005, Paxton 2005, Lovell 2010, Tsuchiya et al. 2015). However, these vegetable production areas are also vulnerable due to the influences of urbanization (Mekvichai et al. 1990).

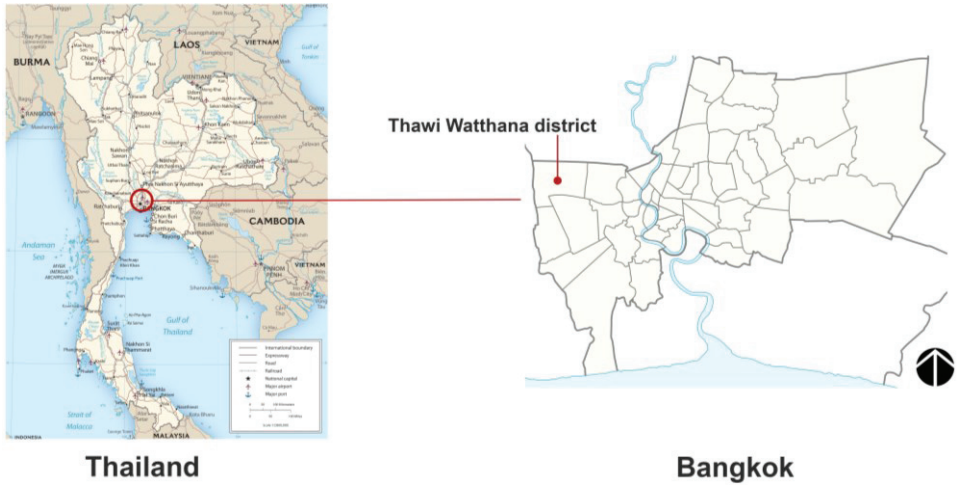


Figure 1. Location of Thawi Watthana District, Bangkok, Thailand. Source: adapted from Wikimedia Commons

Figure 2. Aerial Photograph of Thawi Watthana district. Source: The Royal Thai Survey Department

The decline in peri-urban agriculture has persisted even though there have been land use plans to conserve the agricultural lands in Bangkok. For example, the 2nd

Bangkok's Development Plan (1982-1986) designated agriculture land use, and the Bangkok's Comprehensive Plan (1992–2013) also designated rural and agricultural land use for this district (Bangkok Metropolitan Administration 2014).

Several researchers studied Bangkok's peri-urban agricultural land changes, indicating the ineffectiveness and lack of implementation of land use control (Ross and Poungsomlee 1995, Bello et al. 1998, Yokohari et al. 2000, Askew 2002). Therefore, it is crucial that other factors influencing land use change mechanisms to be investigated. Most of the research focused on rice paddy fields and orchard areas since both of these land uses are a major part of Bangkok's peri-urban agriculture and have particular transformation mechanisms (Hara et al. 2008, Suwanarit 2010, Davivongs et al. 2012, Thongdara et al. 2013). The impact from different factors—such as road, land price, irrigation—are intertwined and vary with specific crops and cultivation methods. Vegetable production areas have been considered as a minor part; therefore, there has been little study on them.

Many previous studies indicated the influence of road construction as a significant cause of the reduction of Bangkok's agricultural area in general (Suttipong 1993, Jongkroy 2009, Suwanarit 2010, Choochuysuwan and Chirapiwat 2013, Jongkroy and Thongbai 2014). However, there has been no thorough study on vegetable production areas in Thawi Watthana district to understand land use changes and landscape fragmentation as influenced by road construction. Located in the low-lying area of the Chaophraya River delta where a continuous ditches-and-dike irrigation system is, these vegetable production areas have shaped a unique landscape. How the road construction caused fragmentation to the vast continuous vegetable production areas affected and the declining process of the vegetable production areas should be investigated.

The working hypothesis of this research was that vegetable production areas in Thawi Watthana district are fragmented by road construction influences, and this has resulted in a decrease in vegetable production areas. Therefore, this research aimed to: 1) understand and determine land use changes to these areas; 2) clarify the landscape configurations of these areas to assess landscape fragmentation; and 3) discuss and recommend land use planning policies and measures to conserve the existing peri-urban agricultural landscape.

Methodology

Vegetable production areas were studied using aerial photographs and satellite images from 1976 to 2015. Previous studies showed that road construction was the main reason for the reduction in agricultural areas (Suttipong 1993, Jongkroy 2009, Suwanarit 2010, Choochuysuwan and Chirapiwat 2013, Jongkroy and Thongbai 2014). Consequently, the starting year (1976) was chosen as this was when the first road construction

commenced in this district. The time interval between aerial photographs or satellite images was approximately ten years with some variation due to the availability of images. Aerial photography from 1976, 1995, and 2002 from the Royal Thai Survey Department, and satellite imagery from 2015 from the Google Earth Pro software (Version 7.1; Google Llc.; Mountain View, CA, USA) were used. A site survey confirmed on-ground position with identified characteristics on the photographs and images such as land use, waterways, and roads. A handheld GPS was used to verify the survey locations.

The aerial photographs and satellite images were digitized and stored in a geographic information system (GIS) database. The data consisted of three thematic map layers: land use, waterways, and roads. Land use comprised: a) the vegetable production area (Figure 3); b) the built-up area; and c) others, which included other types of agricultural lands such as paddy fields and fruit orchards.

(a) *(b)*

Figure 3. Clarification of vegetable production areas on (a) satellite images (Google Earth Pro) and (b) on-site, to create the GIS land use thematic map

This GIS database helped to clarify land use proportions, changes in vegetable production areas and land configurations during different periods from 1976 to 2015. The steps followed procedures available in the Spatial Analyst toolbox of the ArcGIS software (Version 10.3; ESRI Inc.; Redlands, CA, USA):

1) *Land use proportion analysis* determined the amounts (in hectares) of land in vegetable production areas, urbanized areas, and roads. Then, the percentage area of these three types of land use was calculated by comparing them.
2) *Vegetable production area analysis* focused on the land conversion rate. The rates of vegetable production land conversion (hectares per year) were determined and compared with the urbanized area and road area.

3) *Landscape configuration analysis* addressed landscape fragmentation in terms of patch number (PN), patch density (PD), and mean patch size (Area_MN) (Leitão et al. 2006).

PN is an index to count the total number of land patches in the study area. These vegetable production land patches are separated by other types of land use. A high PN value indicates land fragmentation, while a low PN value indicates low fragmentation.

PD is the number of land patches in 1 ha. A high PD indicates high land fragmentation. In contrast, a low PD shows low fragmentation. PD was calculated using Equation 1:

$$PD = \frac{PN}{A} * 100, \quad (1)$$

Where A is the area in hectares, and PN is the patch number.

Area_MN is the average size of all vegetable production land patches. A high Area_MN indicates low fragmentation. In contrast, a low Area_MN shows high fragmentation (Qiu et al. 2015). The calculation of Area_MN can be using Equation 2:

$$Area\_MN = Total\ Area/PN, \quad (2)$$

Where Area_MN is the total study area in ha, and PN is the patch number.

Results

Spatial analysis of vegetable production areas in Thawi Watthana (1976 to 2015)

In 1976 (Figure 4), the vegetable production area was 1,342.97 ha (5.8%), followed by built-up area 62.30 ha (1.2%), roads 11.13 ha (0.2%), water 106.15 ha (2%), and others 3,679.64 ha (70.7%). Vegetable production areas were mostly in the northeast of the district, in the Sala Thammasop sub-district, along the Mai, Pho, Bang Tan, and Kwai canals. Small adjacent plots in combination made large, irregular-shaped plots. Other large plots were scattered along both sides of the Thawi Watthana canal, especially to the south, along Bang Phrom and Bang Noi canals, and on the eastern side of Phutthamonthon Sai 2 road. Roads that appeared in 1976 were Sala Thammasop in the north, Phutthamonthon Sai 2 road in the east, and Thawi Watthana road in the west.

In 1995 (Figure 5), vegetable production areas totalled 1,534.75 ha (29.5%), followed by roads 267.93 ha (5.2%), built-up areas 248.53 ha (4.8%), water 161.25 ha (3.1%), and others 2,989.72 ha (57.5%). During 1976-1995 vegetable production areas increased by 191.79 ha at 10.09 ha/year notably in the south along Bang Phrom canal, Bang Noi canal,

and Thawi Watthana-Kanchanaphisek road down to Bang Choek Nang canal on the southern border and also on the southwestern side of Thawi Watthana road (Figure 6).

Figure 4. Distribution of vegetable production areas, built-up areas, water, roads, and others in 1976

Figure 5. Vegetable production areas, built-up areas, water, roads, and others in 1995

Figure 6. Location of gained vegetable production area during 1976-1995, in Sala Thammasop and Thawi Watthana sub-districts

It was also surprising that vegetable production areas increased along Thawi Watthana-Kanchanapisek road, which was improved from a walking lane into an asphalt road in 1982. This fact contrasts with previous research, which found that road construction was the primary cause of decreasing agricultural areas.

Several places recorded a decrease in the vegetable production area, particularly between Kanchanaphisek road (north-south direction) and Phutthamonthon Sai 2 road. Kanchanaphisek road expanded from 1978-2000, while there was no data on the start of Phutthamonthon Sai 2 road, except that its expansion into a 6-lane road finished in 1982.

In 2002 (Figure 7), land use comprised of vegetable production areas 1,106.87 ha (21.3%), built-up areas 495.94 ha (9.5%), roads 393.98 ha (7.6%), water 177.52 ha (3.4%), and others 3,027.86 ha (58.2%). Vegetable production areas decreased by 427.88 ha. In the same period, a short section of Utthayan road construction and the expansion of Kanchanapisek road in the east were completed in 1999, respectively in 2000. However, the loss of vegetable production areas appears quite scattered. Extensive disappearance was between Sala Thammasop and Borommratchachonnani roads in the north and those to the west of Thawi Watthana road. Utthayan and Kanchanaphisek road had only a minor impact on the decrease in vegetable production areas in this period, probably because Kanchanaphisek road was in use earlier.

Figure 7. Vegetable production areas, built-up areas, water, roads, and others in 2002

In 2015 (Figure 8), land use comprised vegetable production areas 630.37 ha (12.1%), built-up areas 655.64 ha (12.6%), roads 562.37 ha (10.8%), water 230.19 ha (4.4%), and others 3,123.62 ha (60%).

Figure 8. Vegetable production areas, built-up areas, water, roads, and others in 2015

The vegetable production area decreased by 476.50 ha. The most distinct losses were along both sides of Thawi Watthana road.

Sub-district level

The number of vegetable production areas in both sub-districts was in a decreasing trend (Table 1). However, during 1976-1995, the vegetable production area in Thawi Watthana sub-district doubled from 383.76 ha to 758.12 ha. This result was different from the Sala Thamasop sub-district, where the vegetable production area always decreased (Figure 9).

Table 1. Vegetable production area at sub-district level

Year	Sala Thamasop sub-district (ha)	Change rate (%)	Thawi Watthana sub-district (ha)	Change rate (%)	Total (ha)
1976	959.15		383.76		1,342.91
1995	758.12	-20.96	776.27	+102.28	1,534.39
2002	491.70	-35.14	614.90	-20.79	1,106.60
2015	250.82	-48.99	379.43	-38.29	630.24

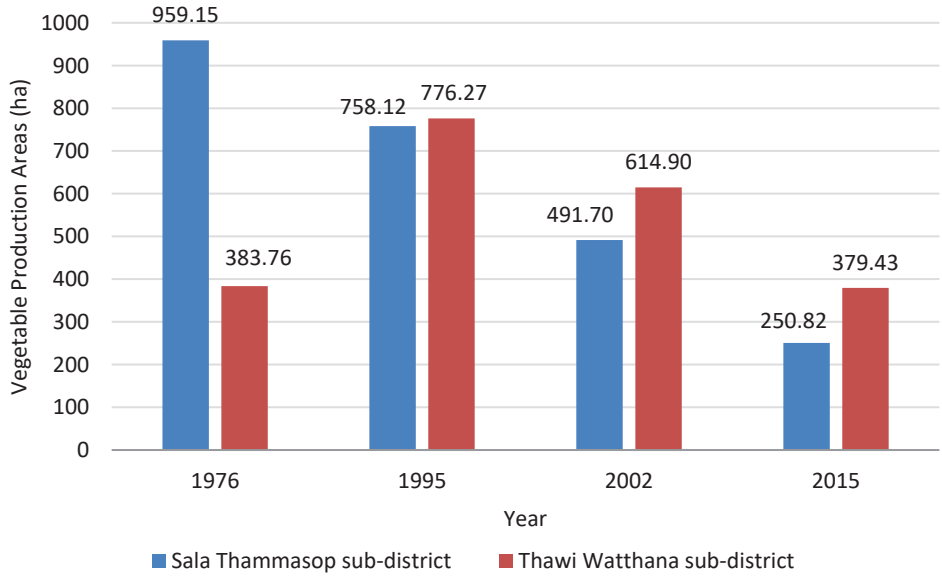
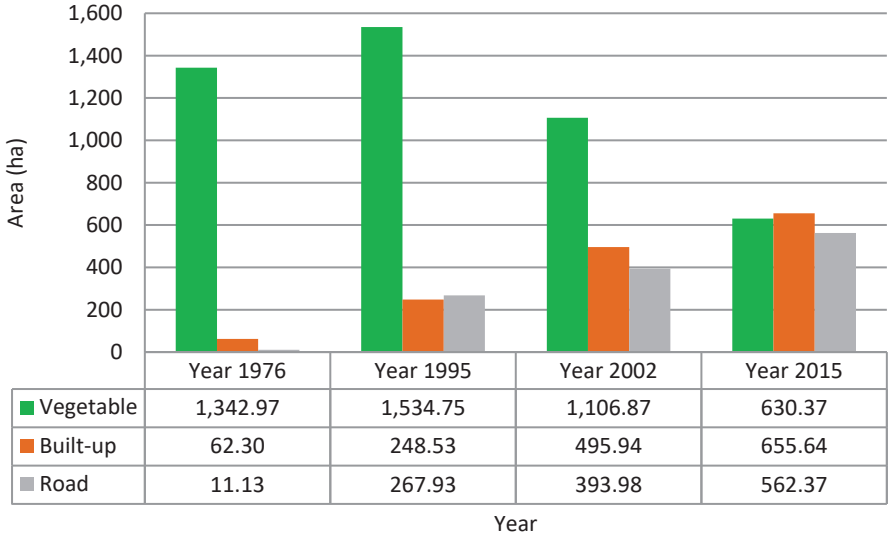


Figure 9. Amount of vegetable production area in Sala Thamasop and Thawi Watthana sub-districts

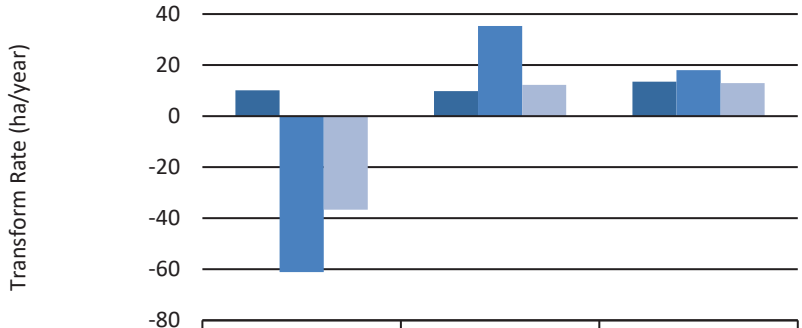
Thawi Watthana district vegetable production area analysis (1976 to 2015)

Vegetable production areas in Thawi Watthana district decreased in general (). However, the change differed in each period. From 1976 to 1995, the area increased with 10.09 ha/year, and after that, it kept decreasing. The highest rate of decrease was during 1995-2002 (61.13 ha/year), while during 2002-2015 it recorded 36.65 ha/year (Figure 11).



	Year 1976	Year 1995	Year 2002	Year 2015
Vegetable	1,342.97	1,534.75	1,106.87	630.37
Built-up	62.30	248.53	495.94	655.64
Road	11.13	267.93	393.98	562.37

Figure 10. Area comparison of vegetable production, built-up, and road (1976-2015)



	Vegetable	Built-up	Road
Year 1976-1995	10.09	9.80	13.52
Year 1995-2002	-61.13	35.34	18.01
Year 2002-2015	-36.65	12.28	12.95

Figure 11. Transformation rates of vegetable production area, built-up area, and road area

The lost areas were to the north in the Sala Thammasop sub-district. In 2015, the vegetable production areas only existed in the southern part of the Thawi Watthana sub-district. In contrast, built-up areas and road areas continuously increased at different rates, which corresponded to the decrease in vegetable areas.

Landscape configuration analysis on vegetable production areas in Thawi Watthana district from 1976 to 2015

Vegetable production areas in Thawi Wattthana district were analyzed to clarify land fragmentation from 1976 to 2015, using landscape configuration indices: patch number (PN), patch density (PD), and mean patch size (Area_MN). The results (Figure 12) revealed that the PN of vegetable production areas had been continuously increasing from 1976 until 2002 and started declining from 2002 until 2015 (PN 1976 = 193, PN 1995 = 545, PN 2002 = 652, and PN 2015 = 351).

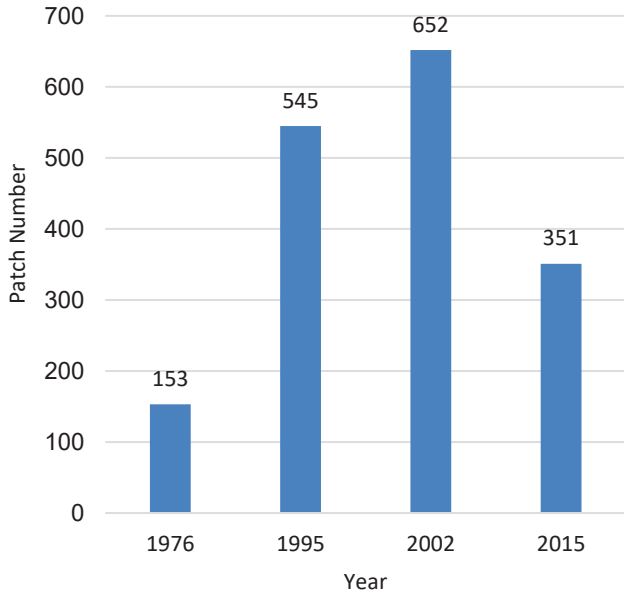


Figure 12. Patch number in 1976, 1995, 2002, and 2015

The patch density analysis results showed a similar pattern to that of the patch number (Figure 13). From 1976 until 2002, the PD had been continuously increasing; it decreased from 2002 to 2015 (PD 1976 = 11.39 patches/100 ha, PD 1995 = 35.51 patches/100 ha, PD 2002 = 58.90 patches/100 ha, and PD 2015 = 55.68 patches/100 ha).

The mean patch size analysis results revealed that the highest Area_MN of 8.78 ha was in 1976. Later, the Area_MN in 1995, 2002, and 2015 was 2.82 ha, 1.70 ha, and 1.80 ha, respectively (Figure 14).

The landscape configuration analysis of vegetable production areas revealed continuously increasing land fragmentation from 1976 until 2002. In the early years, vegetable production patches were large, but they were subsequently divided and became smaller in later years. However, vegetable production areas' fragmentation was lower in 2015, compared with 2002.

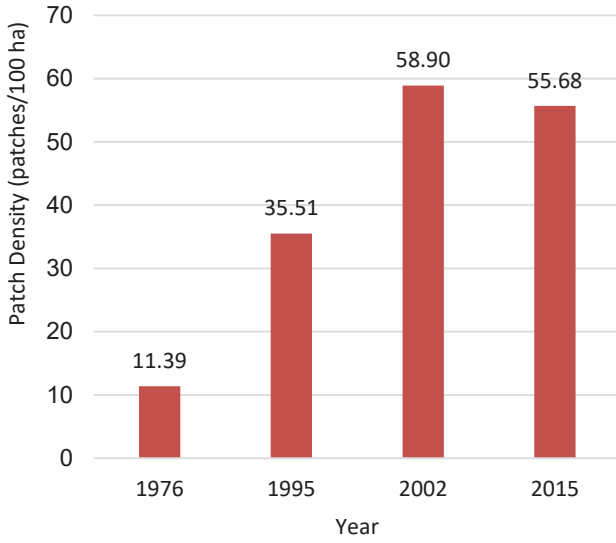


Figure 13. Patch density in 1976, 1995, 2002, and 2015

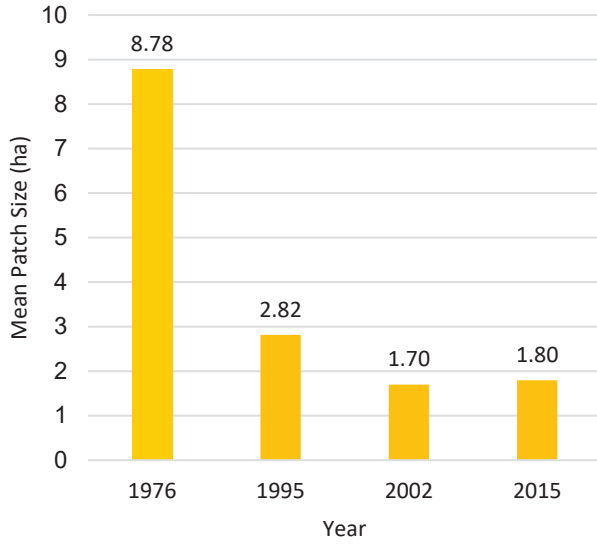


Figure 14. Mean patch size in 1976, 1995, 2002, and 2015

Future trend of vegetable production areas in Thawi Watthana district

The average decreasing rate of the vegetable production area was 20.38 ha/year. Extrapolation using this rate to predict vegetable production areas in the future suggests that all areas will disappear by 2055 (Figure 15).

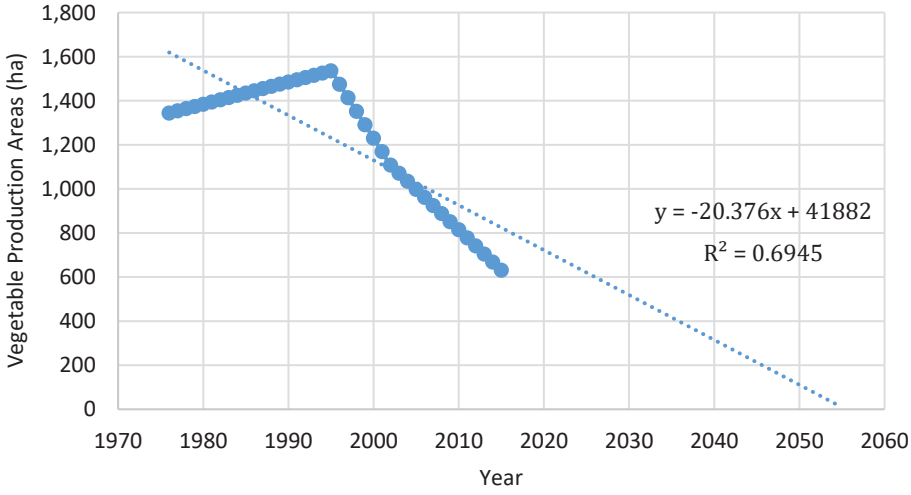


Figure 15. The projected decreasing trend of Thawi Watthana vegetable production areas

Discussion

The results of the spatial analysis in Thawi Watthana district revealed the decreasing trend of vegetable production areas in general in Sala Thammasop and Thawi Watthana sub-districts due to the fact that both are located near the city and on the spot along the urban expansion corridor. These prime vegetable production areas are located in the western fringe area of Bangkok Metropolitan Region, where rapid urban sprawl has taken place on the surrounding agricultural lands (Rimmer 1995, Ooi 2005). Bangkok is Thailand's primary city, and the Bangkok Metropolitan Region is one of the fast-growing mega-urban regions in Southeast Asia (Falkus 1993, Short and Pinet-Peralta 2009, Grossman et al. 2015). These agricultural lands losses have not only occurred on the western fringe where fruit orchards and vegetable production areas are, but they also happened on the northern and eastern boundary, where rice paddy fields are, and on the southern edge, where fish ponds are (Chomchan et al. 1990). However, transportation routes have a significant influence on the agricultural land loss on the overall fringe area of Bangkok.

Transportation routes, especially roads, have exerted a considerable influence on urban development in the Bangkok Metropolitan Region (Bangkok Metropolitan

Administration 1996). There has been rapid urban development (housing estates, commercials, factories, and warehouses) along the major transportation routes leading to the Bangkok city center (Ooi 2005). The remaining agricultural lands along the road have deteriorated due to the spillover from urban sprawl (Mekvichai et al. 1990, Davivongs et al. 2012).

The findings from the spatial analysis are conformable to the working hypothesis that vegetable production areas in Thawi Watthana district decreased earlier in the areas closer to roads. At sub-district level, Sala Thammasop sub-district, where Borommaratchachonnani road, a primary route, cuts through in east-west direction, leading to the center city, continued losing its vegetable production areas and with the road construction, the rate accelerated. The decrease in vegetable production areas in the Thawi Watthana sub-district started in a later period (1995-2015), due to its greater distance from the Borommaratchachonnani road.

The construction of primary roads and later secondary roads affected the landscape structure of the former agricultural matrix. Vast continuous vegetable production areas have been fragmented over time and started with the construction of these road networks. The 50 m-wide road of Borommaratchachonnani is a major transport corridor and an infrastructure for urban development. On the contrary, it is also a significant disturbance corridor that disaggregated the vegetable production matrix as a result of the corridor width effect (Forman and Godron 1991). The results from the landscape configuration analysis (determined by the increase in patch number and patch density and the decrease in mean patch size) revealed a continuously increasing trend of land fragmentation from 1976 until 2002. The road network which cut through the vast vegetable production areas of Thawi Watthana district could have initiated the urban development process. Regarding land economic value, road accessibility with lower land prices attracted real estate developers to purchase these roadside vegetable gardens to develop their housing estate projects (Rondhi et al. 2018). This urban development along the road network involved disturbance patches in the former matrix of vegetable production areas.

These effects of urban sprawl that made agricultural land changes coincide with other cities. In Puerto Rico, during 1977-1994, urbanization increased with 42%, and almost all took over the existing agricultural land (Del Mar López et al. 2001). Urbanization caused a significantly decreased food supply to the people (Forman 2014). In the mega-urban regions of Jabotabek and Bandung of Indonesia, 15,900 ha of prime agrarian land of rice paddy fields has transformed into housing and industrial use during 1980-1989 and continued (Dharmapatni and Firman 1995). Agricultural lands on the western coastal plain of Taiwan, where five major cities (Taipei, Hsinchu, Taichung, Chiayi, Tainan, and Kaohsiung) are located, were found to include almost 20% of agricultural land converted to urban land during 1971-2006 and most of the new farmland became

smaller patches (Lee et al. 2015). This urban sprawl that occurred in various cities caused not only agricultural land loss but also land fragmentation (Carsjens and Van der Knaap 2002).

Conclusions

The decline of vegetable production areas in Thawi Watthana district is severe and it could lead to its complete loss by 2055. On the analysis of vegetable production area changes, data from aerial photographs and satellite images during 1976-2015 indicated that vegetable production areas in the district have been in a decreasing trend, especially since 1995. They fell at an average rate of 20.38 ha/year. The landscape configuration analysis on vegetable production areas, precisely land fragmentation, indicated the occurrence of the urban encroachment process on the vegetable production areas. The study of land fragmentation characterized by the patch number, the patch density, and the mean patch size revealed a continuously increasing land fragmentation from 1976 until 2002.

Even though this district was designated as an agricultural area since the second Bangkok Plan (1982-1986) and through the four other Comprehensive Plans in 1992, 1999, 2006, and 2013, this was unable to prevent the reduction of its vegetable production areas. This study suggests that relying only on the plan is not sufficient to protect the loss of peri-urban agricultural areas. Although a GIS database is one useful tool to monitor and analyze physical changes, other factors and measures are also important. The monitoring system on the fragmentation of agricultural lands is essential as a database to find suitable measures to control urban sprawl in various cities. Further studies should be conducted to understand other factors behind these changes, which will lead to effective preservation measures of vegetable production areas. Above all, since urban agriculture is a complicated issue, the public realization of its importance is one of the critical factors that support the preservation of existing agricultural lands in urban and peri-urban areas. Knowledge distribution is one measure that can be done immediately.

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