Identification of Urban Expansion Patterns in Bangkok Metropolitan Region Through Time Series of Landsat Images and Landscape Metrics

Chudech Losiri[1(✉)] and Masahiko Nagai[2]

[1] Department of Geography, Faculty of Social Sciences, Srinakharinwirot University, Sukhumvit 23, Bangkok 10110, Thailand
chudech@g.swu.ac.th

[2] Graduate School of Sciences and Technology for Innovation, Yamaguchi University, 2-16-1, Tokiwadai, Ube, Yamaguchi 755-8611, Japan

Abstract. Urban expansion has different patterns which affect land development and police planning. Increasing in the number of the population puts force to expand the built-up areas in the Bangkok Metropolitan Region (BMR) predominantly in vicinities of Bangkok, which causes several problems in terms of physical and social aspects. Therefore, understanding the pattern of the urban expansion is a key challenge to allocate enough infrastructure and respond to the land demand for inhabited people in this area. The classification of the pattern of urban expansion analyzed from Landsat5-TM images in 1988, 1993, 1998, 2003, 2008, 2011, and 2014 respectively. The urban area, built-up construction, was mainly extracted by supervised classification and was analyzed patterns using spatial landscape metrics. The result could be found that the origin of the urban area of the BMR was established in the east of the Chao Phraya River with a clustered or radial settlement. Each province of the BMR is extended from the urban area itself, from the center of the city, and is also connected together via the main road as a linear settlement. Finally, a dispersed settlement could be discovered in the areas which are far away from the road network like an urban sprawl.

Keywords: Urban expansion · Patterns · Landsat · Landscape metrics · Bangkok Metropolitan Region

1 Introduction

Urban growth is an interesting phenomenon on the Earth surface which spotlights to a number of people related in the field of urban planning, geography, and geoinformatics. It is an increase of urban features physically resulted from increasing in the number of population living and working the city [1]. There are many processes of change involved in such as economic, demographic, politic, culture, social, technology, and environment. The effects of the urban growth can be yielded on the urban system, land use, building environment and townscape, social ecology, and urbanism [2]. To understand the urban

S. Monprapussorn et al. (Eds.): ICGGS 2018, SPRINGERGEOGR, pp. 32–45, 2020.
https://doi.org/10.1007/978-3-030-33900-5_4

growth, several research scholars have addressed through studies of urban expansion patterns because they can measure directly directions and areas of the urban.

The most important aspect of monitoring the urban growth patterns is demonstrated by lots of numbers of works from the long history [3–5]. For instance, earlier, several research scholars used models such as concentric, sector, and multiple nuclei models to understand the pattern of the city [6]. However, those methods are based on the basic knowledge of economic theory which is quite difficult to comprehend in the real world currently. Moreover, some studies used population density and housing price to explore the urban expansion like von Thünen who developed the spatial-explicit model from the land use to analyze a spatial structure of the city [7].

Due to the advanced technology of satellites from the remote sensing system, the satellite images can provide significant data of the land use and land cover change and their impacts at various spatial scales [8]. In addition, the satellite image can support users to observe and map the urban area for a recent year [9]. The characteristics of the remote sensing data including temporal, spatial, spectral resolutions are useful to remark the spatial-temporal of the urban growth and expansion [10]. The pattern of the urban expansion is an interesting and challenging topic for spatial planners to identify a type [11]. The urban expansion pattern also gives the information to allocate enough infrastructure to respond the demand of people in this area.

To detect the pattern of the urban expansion, many studies are focusing on using images obtained from the remote sensing data. Visual interpretation becomes one of the well-known methods which geographers and spatial planners always use to identify the pattern according to the settlement theory such as cluster, linear, and dispersion. However, other studies suggest that a quantitative method should be applied [12]. Landscape metrics are quantitative approach usually adopted to study in the landscape ecology which reflect the consequence of ecological processes in a specific site [11]. Moreover, many researches have confirmed that they are highly potential schemes to analyze urban expansion patterns [12].

In this study, Bangkok Metropolitan Region (BMR), a big agglomerated-urbanized area of Thailand, consisting of six provinces; Bangkok Metropolis, Nonthaburi, Samut Prakan, Pathum Thani, Samut Sakhon, and Nakhon Pathom, was analyzed the pattern of the urban expansion through the time series of Landsat image from 1988 to 2014 using landscape matrices from FRAGSTATS. The outcome of this study can be delivered to the spatial planning unit or the relevant organizations to improve and understand the urban growth situation in this area.

2 Landscape Metrics and Their Applications in Urban Area

2.1 Landscape Metrics

Landscape metrics are one of the spatial metrics which is used to measure quantitatively to assess spatial characteristics of forms and structures. They have been applied since the 1980s in the field of landscape ecology to identify the pattern and shape of vegetation [12]. The environment protection and resource conservation are two main consideration in the field of landscape ecology focusing on undeveloped natural areas and on the spatial implications of ecological processes in landscapes. These metrics are used to determine the effect of system interaction in a varied landscape from the structure change, numerical comparison of landscapes, and the recognition and monitoring the landscape change [13]. Therefore, landscape metrics have traditionally been used to quantify several aspects of landscape configuration and composition, focusing primarily on types of land cover rather than land use [12].

2.2 Applications of Landscape Metrics in Urban Area

Landscape metrics have been increasingly considered to apply to the urban pattern study. Several studies used the adapted landscape metrics called spatial metrics to identify the urban spatial characteristics [11, 12, 14, 15]. Other studied also linked them with economic processes to see the change in land use patterns and also integrated with urban growth models [14].

Cliftion et al. [16] explained that the spatial landscape metric, which is adapted from the landscape ecology, use the data gathered from aerial photography and satellite remote sensing. The metrics use patches which are polygons with similar characteristics for a specific property of the landscape as a basic unit for analysis. In order to determine a spatial pattern of the urban expansion, there are four categories of the metrics which are always applied for quantifying. The detail of each metric can be elaborately explained in detail as follows [12].

(1) Shape irregularity consists of metrics which assess the physical form of an urban settlement. The general form can be divided into a regular or even shape and a complex shape with a ragged edge. These metrics can be characterized as a single patch (fractal dimension or shape index) or a complex landscape level (landscape shape index, edged density or area-weighted mean patch (AWMP) fractal dimension). In general, the metrics usually implemented to detect the shape irregularity are area-weighted mean patch (AWMP) fractal dimension, edge density, area-weighted mean (AWM) shape index and landscape shape index.
(2) Fragmentation metrics are used to measure the extent of the urban settlement or patches which are close to each other (aggregated) or dispersed (fragmented). These metrics are used at the landscape level. A fragmented landscape is normally characterized by a higher number of patches, with a smaller average size located further away from each other. The metrics mostly used to measure fragmentation are mean patch size, the number of patches, patch density and contagion index.
(3) Diversity metrics pay attention to the urban landscape composition rather than to its shape. The famous metrics are Shannon's diversity and evenness indexes, which measure the distribution of different patch types (such as land use types) throughout the urban area. Patch size standard deviation measures whether the size of the patches varies considerably across the urban area. It may be considered a diversity measure, although it focuses on spatial configuration.
(4) Other metrics include the largest patch index, measuring the relative importance of the largest patch (which may be useful to study, for instance, the importance of the urban center), and the compactness index, which uses concept of compactness based on both fragmentation and shape irregularity.

3 Data and Methodology

In order to analyze the pattern of urban expansion of BMR, this study implemented several processes. The first one was mapping the built-up area to identify the extended urban zone of BMR from the time series of satellite images. The second was a selection of the spatial landscape metrics. The third was the identification of the urban expansion pattern. Each process can be detailed as follows and the overall operation of the methodology is shown in Fig. 1.

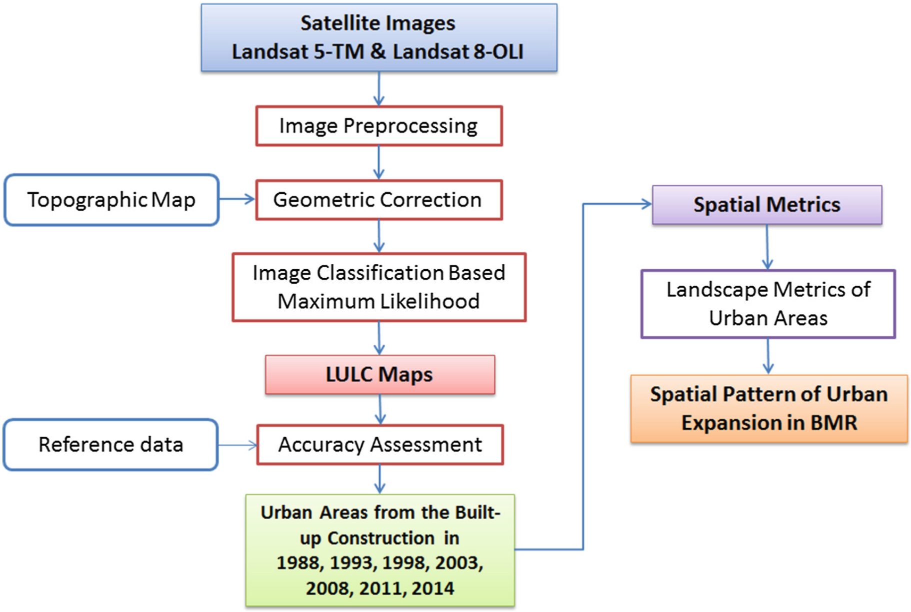


Fig. 1. Overall operation of the methodology

3.1 Urban Land Use Maps for the Bangkok Metropolitan Region

Mapping the urban area of the BMR is the most important process of this objective. The time series of the Landsat data, acquired from the U.S. Geological Survey (USGS) via the USGS Global Visualization Viewer site, were utilized in this study. The six periods of satellite images were generated using the Landsat 5-TM images in November of 1988, 1993, 1998, 2003, 2008, and 2011 and by Landsat 8-OLI image for 2014 of path/row 129/50 and 129/51. After the mosaic process, a couple of the images in the same year applied a geometric correction and re-projection into a common UTM zone 47 North. The first 2014 Landsat image was geo-reference using topographic map from the Royal Thai Survey Department (RTSD). Then the other images were corrected through an image-to-image rectification method based on the corrected 2014 image. The total root mean square error (RMSE) of each image was assessed to confirm the geometric error, which was less than one pixel. Furthermore, the Landsat images were classified into land use maps by maximum likelihood method. Additionally, the accuracy assessment was implemented to confirm the quality of the classified maps through the overall accuracy. Finally, the built-up area from the classification results were extracted to generate urban land use maps in each specific year.

3.2 Set of Spatial Landscape Metrics

For the quantification of the urban expansion patterns, a set of spatial landscape metrics was selected. As mention earlier about the influence of landscape metric, several metrics were selected based on the purpose of this research. This study selected seven metrics from the basic information that proposed by O'Neill et al. [17], McGarigal et al. [18], and Rempel et al. [19]. The list of and detail of each metrics are shown in Table 1.

Table 1. Selected metrics for the analysis of urban expansion pattern.

Metrics	Description	Units	Range
Total Class Area (CA)	The total area of all urban patches. Changes can be identified over time with CA	Hectares	CA > 0, no limit
Number of patches (NUMP)	The number of urban patches in the landscapes	None	NP $\geq$ 1, no limit
Mean Patch Size (MPS)	The calculation of the average mean surface of patches	Hectares	MPS > 0, no limit
Edge density (ED)	The sum of the lengths of all edges segments involving the urban patch type, divided by the total landscape area	Meter/m^2	ED $\geq$ 0, no limit
Mean shape Index (MSI)	The measurement of the ratio between the perimeter of a patch and the perimeter of the simplest patch in the same area	None	MSI $\geq$ 1, no limit
Area weighted mean shape index (AWMSI)	Area weighted mean value of the fractal dimension values of all urban patches, the fractal dimension of a patch equals two times the logarithm of patch perimeter divided by the logarithm of patch area; the perimeter is adjusted the raster bias in perimeter	None	AWMSI $\geq$ 1, no limit
Mean Nearest Neighbor (MNN)	The measurement of the average distance between urban patches of the same patch type	None	MNN $\geq$ 0, no limit

Source: Megahed, Cabral, Silva, and Caetano [20]

3.3 Identification of Urban Expansion Pattern

The identification of the urban expansion pattern had been done through the analysis of FRAGSTATS using Patch Analyst 5.0 built in ArcGIS software [19]. In this study, the urban maps over 26 years (1988 to 2014) were utilized to calculate spatial metrics. The procedure for interpretation of each metric is displayed in Table 2.

Table 2. The urban spatial process analysis from the spatial metrics

Metric	Interpretation	Urban expansion process
Total Class Area (CA)	Changes can be identified over time with CA	–
Number of patches (NUMP)	If NUMP value increases, it is understood fragmentation increases in the field	Aggregation
Mean Patch Size (MPS)	Inverse tend to the NUMP	Aggregation
Edge density (ED)	High ED: ragged ED decreases when urban areas fuse together and boundaries dissolve and increase with new nuclei	Compaction
Mean shape Index (MSI)	MSI is equal to 1 when all patches are circular, and it increases with increasing patch shape irregularity	Compaction
Area weighted mean shape index (AWMSI)	The average shape index of patches of the correspondent type, weighted by patch area, so that large patches weigh more than small one	Compaction
Mean Nearest Neighbor (MNN)	If MNN increases, it reflects greater isolation	Dispersion/Isolation

Moreover, the urban spatial process, resulted from the spatial metrics, was analyzed to determine the state of the urban expansion (Table 2). The spatial urban expansion process can be divided into three processes such as:

(1) Aggregation corresponds to the clustering of patches from the patches size. The decreasing in the total number of patch (NUMP) can increase in the mean patch size (MPS). The aggregation process was analyzed by mean of integrating the evolution of the NUMP and MSP.
(2) Compaction involves in the formation of rounded patches such as a circular shape that make them more compact. The inversion of the compaction is an elongation (or linear shape) which the patch shape becomes more elongated. By this process, the edge density (ED), mean shape index (MSI), and area weighted mean shape index (AWMSI) were calculated to indicate the compaction. The lower values from three metrics indicate the high compaction. On the other hand, the higher metric values indicate elongated shape.

(3) Dispersion or isolation involves increasing of the distance which separates patches from the same land use class. It can be measured by a mean nearest neighbor (MNN). The high value from the metric shows a greater isolation which indicates greater dispersion as well.

4 Result and Discussion

4.1 Mapping the Urban Land Use of BMR

After the maximum likelihood classification process, the urban land use maps from the Landsat images were created for seven time periods from 1988 to 2014. It can be seen obviously from the Fig. 2 that the origin of the urban expansion was located in the center of Bangkok Metropolis and then expanded according to the national plan policy of the country and development of transportation networks. This area is also known as the biggest urban agglomeration of Thailand. In addition, the total urban area was increased dramatically from about 600 km^2 in 1988 to 3,060 km^2 in 2014 (Fig. 3(a)). However, there was a slightly decrease in the number of the urban area in two periods (e.g. 2003–2008 and 2011–2014) (Fig. 3(b)).

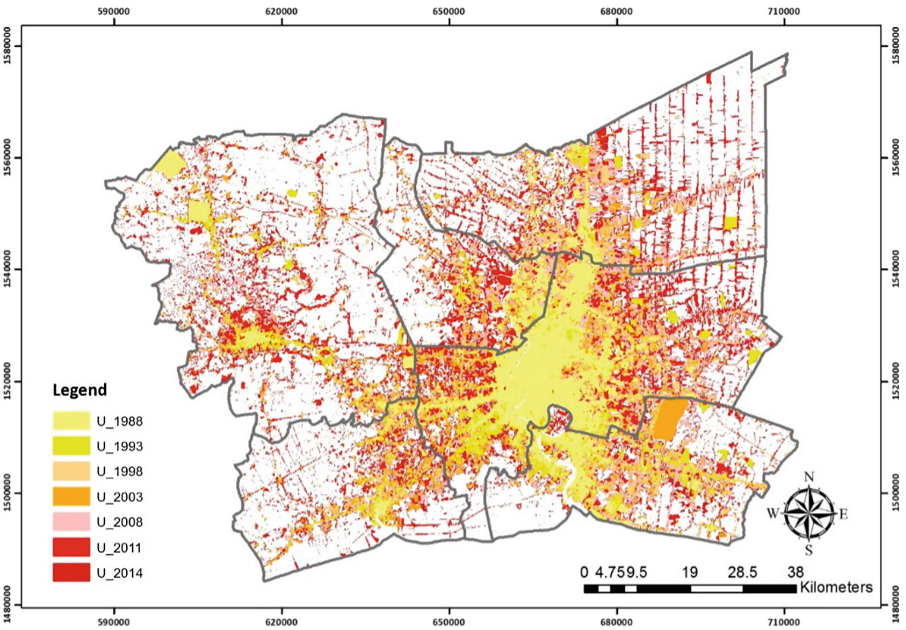
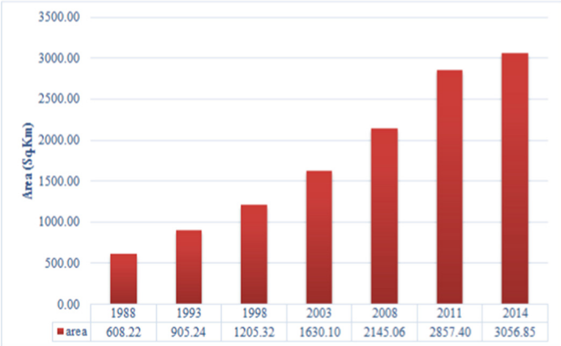


Fig. 2. Urban land use map of BMR in 1988, 1993, 1998, 2003, 2008, 2011, and 2014



(a)

Year	Growth rate
1998-1993	0.212
1993-1998	0.208
1998-2003	0.209
2003-2008	0.207
2008-2011	0.346
2011-2014	0.336

(b)

Fig. 3. (a) The total number of the urban area (b) the growth rate of the urban land use.

4.2 Urban Expansion Pattern

To analyze the pattern of the urban expansion in BMR, this study applied seven spatial landscape metrics, CA, NUMP, MPS, ED MSI, AWMSI, and MNN, to evaluate the urban spatial process and pattern at the patch level. The result from the analysis of this section can be divided into two scales. The first is analyzing the pattern as a whole of BMR. The second is analyzing the pattern as individual provinces. The result of each analysis is given in detail as follows.

Bangkok Metropolitan Region (BMR). The CA metric indicated that there was an increase in the number of the urban area throughout the period of study. The NUMP dramatically increased from 1988 to 2003. However, the values slightly decreased in 2008 and continued increased again in 2011 and slightly decreased in 2014. On the other hand, the all values of the MPS showed the reversed trend of the NUMP. It suggests that BMR slightly decreased in the aggregation. In the aspect of compaction, the ED and AWMSI values showed increasing numbers. It means the urban area expanded year by year with a complex shape. The result from the MSI metric displayed a value greater than 1. It also confirmed that the urban shape was irregular. Moreover, the value of MNN indicated a downward trend which implied the BMR facing a low dispersion (Fig. 4).

Bangkok Metropolis. The CA metric indicated that there was an increase in the number of the urban area throughout the period of study like the BMR. The NUMP dramatically increased from 1988 to 2003, fell down in 2008, and remained stable until 2014. On the other hand, the all values of the MPS metric showed the inversion trend of the NUMP. It suggested that in the later state BMR had more aggregation of the urban area. In the aspect of compaction, the ED and AWMSI values showed a fluctuation. It seems that the urban area increased regularly; however, the shape of the urban of Bangkok Metropolis was not stable (mixed between compact and elongated). The MSI metric showed a value greater than 1. It also confirmed that the urban shape was irregular. Moreover, the value of MNN indicated a downward trend which indicated a low dispersion (Fig. 5).

Fig. 4. Trend of the spatial landscape metric of BMR

Fig. 5. Trend of the spatial landscape metric of Bangkok Metropolis

Nakhon Pathom. The CA metrics showed an urban expansion of Nakhon Pathom from about 5,000 to 50,000 m^2 in 26 years. The NUMP dramatically increased from 1988 to 2008 and continued to soar to 2,500 in 2014. By contrast, the MPS illustrated the inverted value from the NUMP. It suggest that this province was slightly fragmented. For the compaction, the ED increased from 2 to about 25. Moreover, there was a fluctuated increase in the AWMSI. Both metrics implied that the urban zone always increased with the complex shape especially in 2011 and 2014. All MSI values were greater than 1. Therefore, the urban shape was also irregular. In terms of dispersion, the MNN was on the decline, which means this province had a low dispersion because the urban expansion trend of Nakhon Pathom was close to the urban core (Fig. 6).

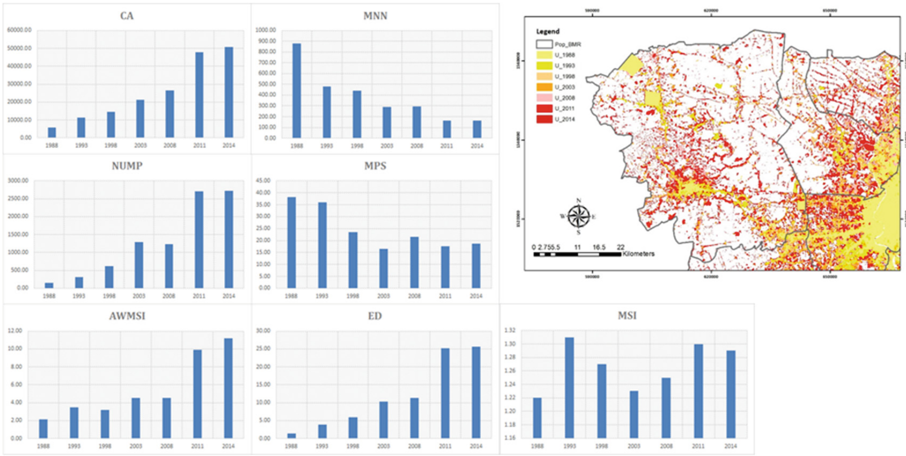


Fig. 6. Trend of the spatial landscape metric of Nakhon Pathom.

Nonthaburi. The trend of the CA showed the same situation as two aforementioned provinces, which dramatically increased from 1988 to 2014. The NUMP indicated that the urban area had increased since 1988 to hit the highest at around 500 in 2003 and declined to about 400 in 2014. Moreover, the MSP also confirmed it was aggregated in the first year of study and then declined to the lowest at 2003 and continued increase to above 70 in 2014. Both NUMP and MSP metrics implied that Nonthaburi had more aggregation especially in the southern-west of the province. In case of compaction, the ED and AWMSI illustrated the increasing number throughout the study period. It implied that there was a high compaction in this area. In addition, the shape of the compaction was irregular as the MSI metric yielded a value greater than 1. From the analysis of MNN, there was an isolation of the urban area in the first-two times. However, the isolation radically decreased into below 200 at 2014. The urban expansion trend of Nonthaburi showed a low dispersion (Fig. 7).

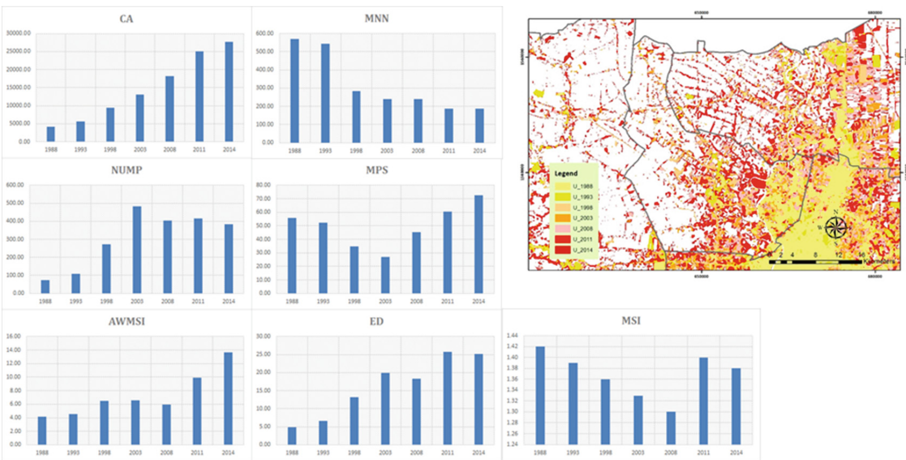


Fig. 7. Trend of the spatial landscape metric of Nonthaburi

Pathum Thani. The urban area of Pathum Thani had expanded continuously as comprehended from the result of the CA metric. The NUMP and MPS illustrated the same situation as the BMR. It implied that the urban expansion of this province slightly decreased in an aggregation. To analyze the compaction, the ED and AWMSI metric was investigated. The results showed the little increase in values of both metrics from 1988 to 2008. Nevertheless, the values from the ED and AWMSI metrics had particularly increased in 2011 and 2014. It means that the urban area expanded in the complex form with a ragged edge and an elongation which showed as the same result evidently from the MSI metric. From 1998 to 2014, the MNN dramatically decreased which reflected that the expansion pattern of this provinces was low dispersion (Fig. 8).

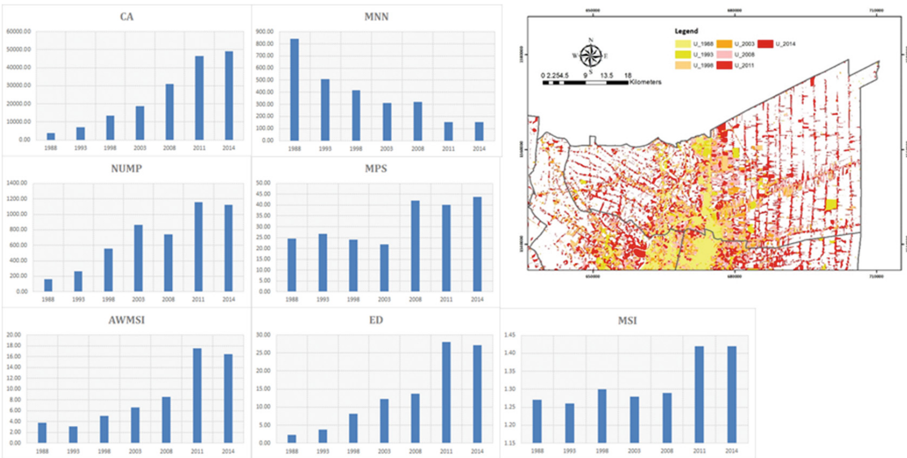


Fig. 8. Trend of the spatial landscape metric of Pathum Thani

Samut Pakan. The urban area was expanded overtime particularly in the adjacent area of Bangkok Metropolis as see from the CA and the map (Fig. 9). The NUMP trend was upward and reached the highest value in 2011. The MPS was fluctuated and then climbed into about 44 in 2014. It could be implied that the urban expansion was an aggregated process. In the compaction aspect, the values of ED and AWMSI rose gradually and climbed sharply in 2011 and dropped slightly in 2014. Moreover, the value of MSI in each year was greater than 1. All of these pointed out that the urban shape of the Samut Prakan was a complex form. The result from the MNN analysis showed a decreased trend and then leveled off. It implied Samut Pakan had a low dispersion (Fig. 9).

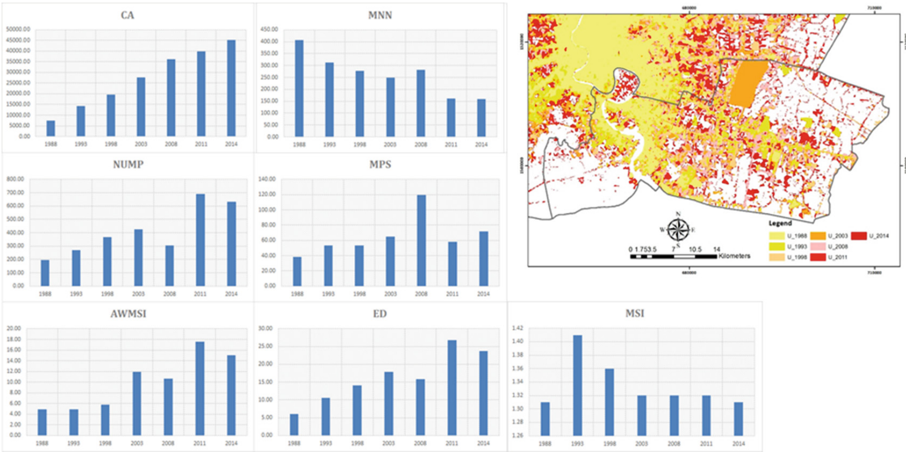


Fig. 9. Trend of the spatial landscape metric of Samut Pakan

Samut Sakorn. The CA value in each year of this province increased noticeably due to the urbanization in the western part of Bangkok Metropolis. The NUMP trend was upward and reached the highest values with 935 in 2011. The MPS was fluctuated and then climbed into about 23 in 2014. It could be implied that the urban expansion was an aggregated process. In the compaction analysis, the ED and AWMSI metrics illustrated the increasing number throughout the study period. It implied that there was a high compaction in this area. The shape of the urban expansion was irregular as the MSI produced the value greater than 1. The MNN of Samut Sakorn province dramatically decreased and reflected that the urban expansion in this province showed a low dispersion (Fig. 10).

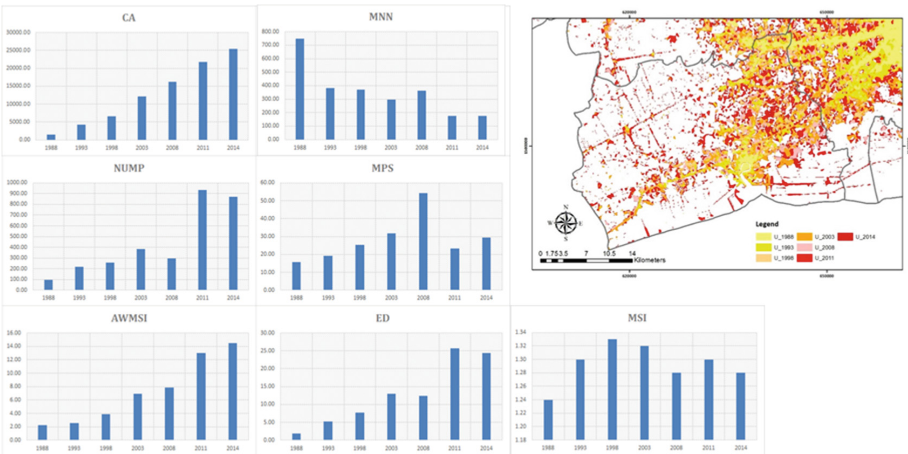


Fig. 10. Trend of the spatial landscape metric of Samut Sakorn

5 Conclusion

In brief, the pattern of the urban expansion in BMR was analyzed through the time series of remote sensing data from Landsat 5 and 8 images between 1988 and 2014. The scientific methodology of the spatial landscape metrics was utilized to see the pattern elaborately by using the patch analysis. Three urban spatial processes were used to analyze the pattern of the urban expansion. The NUMP and MSP metrics were used to identify the aggregated pattern. Moreover, this study investigated the compaction by using ED, MSI, and AWMSI metrics. Furthermore, the dispersion or isolation pattern was examined through the MNN metric. The acquired results illustrate the usefulness of the spatial landscape metrics to classify the spatial pattern of the urban. According to the analysis, it could be found out that the aggregation of the BMR had decreased. On the other hand, the urban areas of the adjacent provinces were an expansion from the center of the city where it did not settle next to Bangkok Metropolis. When diagnosing in detail, however, it could be found that Bangkok Metropolis, Nonthaburi, and Pathum Thani revealed the inverted pattern from the BMR. All urban areas of three provinces were established as a big agglomeration of the region. In case of the compaction, the shape of the urban expansion of the BMR was complex due to the urban areas were expanded apart from the city center via the main transportation network such as main road and other prospective mass transportation. For the dispersion pattern, the result from the analysis confirmed that the BMR had decreased dispersion. All of the urban areas of each province, presently, has expanded itself beyond the political boundary.

From this study, the combination of remote sensing data and spatial metrics yields accurate results and were a good indicator in order to understand the urban expansion pattern. The analyzed results can provide significant suggestions to the urban planners who work on the spatial arrangement of the urban area and infrastructure of the BMR. Moreover, the expansion pattern can be used to control the unplanned settlement such as the urban sprawl which becomes a momentous problem in several countries.

References

1. Aithal, B.H., Ramachandra, T.V.: Visualization of urban growth pattern in Chennai using geoinformatics and spatial metrics. J. Indian Soc. Remote Sens. **44**, 617–633 (2016)
2. Knox, P.L., McCarthy, L.: Urbanization: An Introduction to Urban Geography, 3rd edn. Pearson, Boston (2012)
3. Wu, J., Jenerette, G.D., Buyantuyev, A., Redman, C.L.: Quantifying spatiotemporal patterns of urbanization: the case of the two fastest growing metropolitan regions in the united states. Ecol. Complex. **8**, 1–8 (2011)
4. Wu, J.: Urban ecology and sustainability: the state-of-the-science and future directions. Landsc. Urban Plann. **125**, 209–221 (2014)
5. Liu, Z., He, C., Wu, J.: General spatiotemporal patterns of urbanization: an examination of 16 world cities. Sustainability **8**, 41 (2016)
6. Lin, Y.: Modelling Urban Development with Geographical Information Systems and Cellular Automata. CRC Press, New York (2009)
7. Chang, C.: Understanding spatial and temporal patterns of urban expansion in Western Chuna during the post-reform era, Master thesis. University of Wisconsin-Madison (2013)

8. Johnson, M.P.: Environmental impacts of urban sprawl: a survey of the literature and proposed research agenda. Environ. Plann. A **33**, 717–735 (2001)
9. Poyil, R.P., Misra, A.K.: Urban agglomeration impact analysis using remote sensing and GIS techniques in Malegaon city, India. Int. J. Sustain. **4**, 136–144 (2015)
10. Jensen, J.: Introductory Digital Image Processing: a Remote Sensing Perspective, 4th edn. Pearson, Glenview (2015)
11. Aguilera, F., Valenzuela, L.M., Botequilha-Leitão, A.: Landscape metrics in the analysis of urban land use patterns: a case study in a Spanish metropolitan area. Landscape Urban Plann. **99**(3–4), 226–238 (2011)
12. Reis, J.P., Silva, E.A., Pinho, P.: Spatial metrics to study urban patterns in growing and shrinking cities. Urban Geogr. **37**, 2 (2016)
13. Bhatta, B.: Analysis of Urban Growth and Sprawl from Remote Sensing Data. Springer, New York (2010)
14. Herold, M., Liu, X., Clarke, K.C.: Spatial metrics and image texture for mapping urban land use. Am. Soc. Photogrammetry Remote Sens. **9**, 99–1001 (2003)
15. Schwarz, N., Haase, D., Seppelt, R.: Omnipresent sprawl? a review of urban simulation models with respect to urban shrinkage. Environ. Plan. **37**(2), 265–283 (2010)
16. Clifton, K., Ewing, R., Knaap, G.J., Song, Y.: Quantitative analysis of urban form: a multidisciplinary review. J. Urbanism **1**, 17–45 (2008)
17. O'Neill, R.V., Krummel, J.R., Gardner, R.H., Sugihara, G., Jackson, B.L., DeAngelis, D.L., Milne, B.T., Turner, M.G., Zygmunt, B., Christensen, S.W., Dale, V.H., Graham, R.L.: Indices of landscape pattern. Landsc. Ecol. **1**, 153–162 (1988)
18. McGarigal, K., Cushman, S.A., Neel, M.C., Ene, E.: FRAGSTATS: Spatial pattern analysis program for categorical maps. Computer software program produced by the authors at the University of Massachusetts, Amherst (2002). www.umass.edu/landeco/research/fragstats/fragstats.html. Accessed 15 Mar 2010
19. Rempel, R.S., Kaukinen, D., Carr, A.P.: Patch analyst and patch grid. Ontario Ministry of Natural Resources. Centre for Northern Forest Ecosystem Research, Thunder Bay, Ontario (2012)
20. Megahed, Y., Cabral, P., Silva, J., Caetano, M.: Land cover mapping analysis and urban growth modelling using remote sensing techniques in Greater Cairo Region—Egypt. ISPRS Int. J. Geo. Inf. **4**, 1750–1769 (2015)