9. Analyzing spatiotemporal types and patterns of urban growth in watersheds that flow into Jakarta Bay, Indonesia

by Muhammad Helmi

Remote Sensing Applications: Society and Environment 14 (2019) 170–177

Contents lists available at ScienceDirect

Remote Sensing Applications: Society and Environment

journal homepage: www.elsevier.com/locate/rsase

Analyzing spatiotemporal types and patterns of urban growth in watersheds that flow into Jakarta Bay, Indonesia

Bobby Rachmat Fitriyanto[a,d,*], Muhammad Helmi[b,d,**], Hadiyanto[a,c,***]

[a] Master Program in Environmental Science, Universitas Diponegoro, Semarang, Indonesia
[b] Faculty of Fisheries and Marine Science, Universitas Diponegoro, Semarang, Indonesia
[c] Department of Chemical Engineering, Universitas Diponegoro, Semarang, Indonesia
[d] Center for Coastal Rehabilitation and Disaster Mitigation Studies, Universitas Diponegoro, Semarang, Indonesia

A R T I C L E I N F O

Keywords:
Urban growth
Remote sensing
Spatial metrics
Watershed
Jakarta

A B S T R A C T

Jakarta is the economic hub of Indonesia and the primary target for urbanization. This condition encourages urban growth, particularly in the peri-urban regions of Jakarta. Uncontrolled urban growth impacts Jakarta negatively, because of its location downslope of eight watersheds. This study evaluated the spatiotemporal characteristics and types of urban growth in the watersheds that flow into Jakarta Bay using remote sensing data. Spatial rules revealed three urban growth types, including infilling, edge expansion, and outlying, from 2001 to 2017. Spatial metrics provided quantitative data on urban growth characteristics and explained the spatio-temporal dynamics of urban growth. The study area was divided into eight cardinal directions to analyze urban growth trends. From 2001 to 2017, the average annual urban and population growth rates were 3.75% and 3.9%, respectively. The prominent urban growth types, edge expansion and infilling, coalesced urban patches and rendered urban areas more compact. Results indicated that the North-West (NW) region demonstrated the most orderly urban growth, whereas the East region demonstrated the least.

1. Introduction

Urban growth is the process of changing the spatial structure of a city because of increasing population; this process may be followed by land expansion (Reis et al., 2016). Rapid economic growth in a region is the main driving factor for population and urban growths and may occur in a planned or unplanned manner (Bhat et al., 2017). Urban growth without systematic land use planning characterized by low density is termed urban sprawl (Bruegmann, 2005). The emergence of urban sprawl for a city is the consequence of economic maturity. According to Mosammam et al. (2017), urban sprawl is often associated with a negative socio-economic and environmental impact.

Mumford (1938) states that cities grow through the following six stages: eopolis, polis, metropolis, megapolis, tyranopolis, and necropolis. Spatially, the process of urban evolution comprises the phases of diffusion and coalescence (Dietzel et al., 2005). In the diffusion phase, urban evolution begins with the emergence of urban seeds or cores that become new urban centers. The new urban areas expand and fill the spaces between existing urban lands. The growth of urban lands attains the phase of coalescence when the urban landscape has fully grown.

Considering the phases of urban spatial evolution, Forman (1995) partitioned urban growth into the following three types: outlying, infilling, and edge expansion types. The outlying urban growth is characterized by the diffusion phase while the infilling and edge expansion types reflect the coalescence phase. These three urban growth types are frequently used to analyze urban growth trends and the potential for urban sprawl in a region (Dahal et al., 2017; Shi et al., 2012; Sun et al., 2012). Spatial metrics are employed in the representation of characteristics of urban growth. Research on urban growth characteristics and types continues to evolve alongside remote sensing technology, enhancing the ease of obtaining and quality of information from satellite imagery (Han et al., 2016). According to Clarke et al. (2005), the combination of remote sensing and spatial metrics provides more consistent and detailed spatial information on changes in urban structures.

Jakarta, the capital of Indonesia is one of the largest metropolitan cities in Asia. Its strong economy makes it attractive for Indonesians to live and work. Data from the Statistical Agency of Jakarta (2018)

* Corresponding author. Master Program in Environmental Science, Universitas Diponegoro, Semarang, Indonesia.
** Corresponding author. Center for Coastal Rehabilitation and Disaster Mitigation Studies, Universitas Diponegoro, Semarang, Indonesia.
*** Corresponding author. Department of Chemical Engineering, Universitas Diponegoro, Semarang, Indonesia.
E-mail addresses: bobby.kemenhut@gmail.com (B.R. Fitriyanto), muhammadhelmi69@gmail.com (M. Helmi), hadiyanto@live.undip.ac.id (Hadiyanto).

https://doi.org/10.1016/j.rsase.2019.04.002
Received 17 October 2018; Received in revised form 4 February 2019; Accepted 6 April 2019
Available online 08 April 2019

indicates the population of Jakarta changed from 10.18 million people in 2015 to 10.37 million in 2017. This represents an increase of 269 people per day (11 people per hour) in the population of Jakarta from 2015 to 2017.

The increasing population in Jakarta exacerbates the demand for residential and commercial lands. The Jakarta Metropolitan Area (JMA) also referred as Jabodetabek (Jakarta, Bogor, Depok, Tangerang, Bekasi) experienced massive developments in the last three decades. These involved the transformation into new towns of over 300,000 ha of rural lands in the peri-urban area of Jakarta (Winarso et al., 2015). The Jakarta peri-urban area therefore expanded from about 10 km in 1970 to around 40–45 km from Jakarta in recent times (Winarso et al., 2015).

This expansion exposes Jakarta which is located downslope of eight watersheds to environmental risks including flood disasters, which occur almost annually. Major floods that occurred in Jakarta in 2007, 2013, 2015 and 2018 damaged the economy, with losses estimated in millions of dollars. Therefore, understanding the characteristics and types of urban growth in watersheds of the Jakarta Bay is critical for the formulation of policies to overcome floods and spatial problems in Jakarta and surrounding cities.

This study aims to analyze the spatiotemporal characteristics and types of urban growth in watersheds of the Jakarta Bay using urban land data from remote sensing. The study area was chosen because The hydrological characteristics of the watersheds, which influence 13 rivers in the Jakarta area, provided a rationale for choosing the study area. According to Ali et al. (2016), land use changes, especially in elevated areas, will affect the entire watersheds area and promote flooding in the low-lying areas. Land use changes can disrupt the ecological system of watersheds by causing changes in the distribution of surface runoff, infiltration, interflow and evapotranspiration (Sajikumar and Remya, 2015).

2. Study area

This study comprised eight watersheds of the Jakarta Bay, covering an area of about 443314.5 Ha (Table 1). Geographically, the study area lies between latitudes 06° 00′14.8 "- 06° 47′ 60″ S and longitudes 106° 28′53.5 "- 107° 13′6.6″ E. The downslope area is in the north of the study area with an average slope below 8%. This area is adjacent to the Java Sea and is covered mostly by the Jakarta Province. The south of the study area is the upslope area located in the Bogor District. This upslope area incorporates mountainous areas with slopes of more than 25% and plays an important role as a catchment area.

The administrative boundary data from the Geospatial Information Agency of Indonesia (BIG) situates the study area in Banten (Tangerang Regency, Tangerang City and South Tangerang City), DKI Jakarta (North Jakarta, East Jakarta, South Jakarta, West Jakarta and Central Jakarta) and West Java (Bogor Regency, Bogor City, Depok City, Bekasi Regency, Bekasi City) (see Table 3).

Table 1
Watersheds in the study area with their respective surface areas and relative percentage areas.
Source: Ministry of Environment and Forestry, Indonesia

No	Watershed	Area (Ha)	Area (%)
1	Ciliwung	38610.25	8.71
2	Cisadane	151576.65	34.19
3	Angke Pesanggrahan	48732.38	10.99
4	Bekasi	140845.76	31.77
5	Buaran	8008.18	1.81
6	Cakung	14743.37	3.33
7	Krukut	22392.65	5.05
8	Sunter	18405.26	4.15
Total		443314.50	100

Fig. 1 shows the study area in the JMA or Jabodetabek area. Jabodetabek is an acronym for Jakarta Bogor Depok Tangerang Bekasi, which represents a combination of 13 regencies or cities. The eight watersheds of the Jakarta Bay fall within these cities. Jabodetabek is based on regional administrative boundaries while the study area is predicated on watershed boundaries. Watershed boundaries represent ecological boundaries and are therefore more useful in the development of environmental management plans (Barham, 2001).

3. Materials and methods

3.1. Urban area classification

This study utilized two multitemporal medium resolution Landsat images downloaded from the United States Geological Survey website (http://earthexplorer.usgs.gov). These included a Landsat 7 ETM + image acquired on September 17, 2001, and a Landsat 8 OLI image acquired on August 04, 2017. The spatial resolution of both images is 30 m, making it feasible to analyze urban growth characteristics and types between 2001 and 2017.

The images were geometrically corrected based on the World Geodetic System (WGS Version 1984) projected for Universal Transverse Mercator Zone 48 South. The images were corrected for atmospheric effects using the Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes (FLAASH) model of the ENVI 5.1 software. The FLAASH module is a radiative transfer code model that corrects images by suppressing or eliminating the effects of water vapor, oxygen, carbon dioxide, methane, ozone, molecular, and aerosol scattering based on the radiation transfer code MODTRAN-4 (Danoedoro, 2012). Modtran-4 uses the adjacency effect calculation to correct the reflectance value for reflections from surrounding objects (Mathew et al., 2003).

The Urban Index (UI) was employed to delineate urban pixels in the study area. The UI is a spectral transformation method to generate built-up areas using shortwave infrared (ρSWIR2) and Near Infrared (NIR) bands. The UI produced better urban land maps of the study area relative to other spectral transformations including the Normalized Difference Built-up Index (Zha et al., 2003), the Index-based Built-up Index (IBI; Xu, 2008), and the New Built-up Index (Chen et al., 2010). The UI values were determined from the relation in Kawamura et al. (1996) given as follows:

$$UI = \frac{\rho SWIR2 - \rho NIR}{\rho SWIR2 + \rho NIR} \quad (1)$$

The UI maps resulted in urban and non-urban land use classifications. This was achieved through a supervised classification method relying on a maximum likelihood algorithm of the ENVI 5.1 software. According to DudaHart and Stork (2000), the maximum likelihood employs various classification decisions using probability and cost functions, categorizing each pixel into its correspondence class. Although the Urban land use classes represented the entire built up the urban land data necessitated improvement because of some misclassifications. We corrected the misclassifications through a visual interpretation method on true composite Landsat imagery with the aid of high-resolution images from Google Earth.

The confusion matrix and Kappa statistical test permitted testing of the accuracy of the land use classification. These techniques have previously demonstrated their effectiveness in land use classification (Lillesand and Kiefer, 2005). A hundred urban pixel points from the classification results were chosen randomly and tested for accuracy through ground checks and high-resolution satellite imagery from Google Earth. The overall classification of the urban area yielded 93% for 2001 and 94% for 2017. The kappa coefficients determined for urban areas consisted of 0.86 for 2001 and 0.88 for 2017.

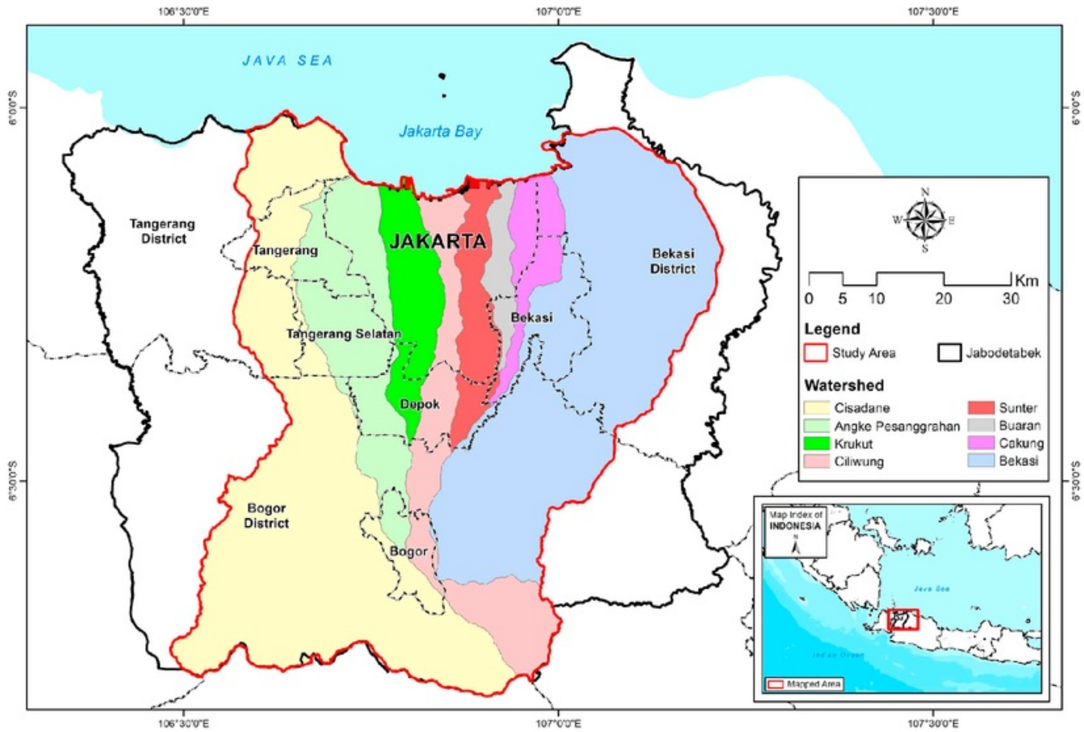

Fig. 1. Study area map.

3.2. Urban growth types

The urban land maps in 2001 and 2017 enabled the generation of a map of urban growth. This urban growth map resulted in three types namely; infilling growth, edge expansion and outlying growth. The infilling growth is a type of urban growth where gaps are filled between existing urban land. The edge expansion is a type of urban growth that involves an extension from the edge of an existing urban land. The outlying growth is a type of urban growth that emerges separately from an existing urban land. In this study, urban growth types were analyzed according Shi et al. (2012) using the following steps:

1. The polygon maps of existing urban patches were converted to polyline maps, and then, the polyline maps were converted back to polygon maps. This process eliminated perforations in the polygon maps of existing urban patches. Furthermore, the polygon maps were overlain with the polygon maps for urban growth. An ID of 1 was assigned to a newly developed urban patch that coincided with an existing urban patch, otherwise an ID of 0 was assigned.
2. Analyses of 1-m-wide buffer zones were conducted on polygons with an ID of 0. The buffer zone analysis aimed to determine the P value; Where the P value represents the proportion of the existing urban patch in the buffer zone of the newly developed urban patch.
3. Determination of the types of urban growth including:
   a. ID = 1 representing infilling growth
   b. ID = 0 and P value > 50% representing infilling growth
   c. ID = 0 and P value ≤ 50% representing edge expansion
   d. ID = 0 and P value = 0 representing outlying growth

3.3. Spatial metrics

Spatial metrics were used to analyze urban growth characteristics with the Fragstats 4.2 software (McGarigal et al., 2012). We selected 5 metrics including the number of patches (NP), the mean patch size (MPS), the large patch index (LPI), the edge density (ED), and the euclidean mean nearest neighbor (ENN_MN) listed in Table 2. These metrics were chosen based on the research needs and knowledge from previous research studies quantifying the characteristics of urban growth (Dasgupta et al., 2010; Bekalo, 2009; Lal et al., 2017; Akintunde et al., 2016; Dahal et al., 2017; Helmi et al., 2018).

3.4. Directional analysis

To analyze the urban growth trends in various directions, the urban growth types and spatial metrics were assessed based in the North (N), Northeast (NE), East (E), Southeast (SE), South (S), Southwest (SW), West (W) and Northwest (NW) directions.

4. Results

4.1. Evolution of urban growth types

The mapping and the measurement of urban land revealed that the urban area studied covered 81,335.91 Ha in 2001 and 132,099.68 Ha in 2017 (see Fig. 2). This indicates an increase of 50,763.77 Ha in 16 years (3,172.74 Ha/year). The Bekasi watershed which increased by 29.84%, the Angke Pesanggrahan watershed which changed by 22.20% and the Cisadane watershed that expanded by 18.37% represent the watersheds with the highest urban growth in the study area. Data from the Statistics Agency of Indonesia indicates a population of 18,923,333 in 2001 and 30,289,472 in 2017. This amounts to a 3.74% annual population growth rate from 2001 to 2017. This population growth rate is close to the urban growth rate of 3.9% per year from 2001 to 2017.

Fig. 4a illustrates that the Northwest (NW) and the Northeast (NE) regions represent the areas with the highest urban growth. The urban growth rates in these regions are equivalent to the population growth

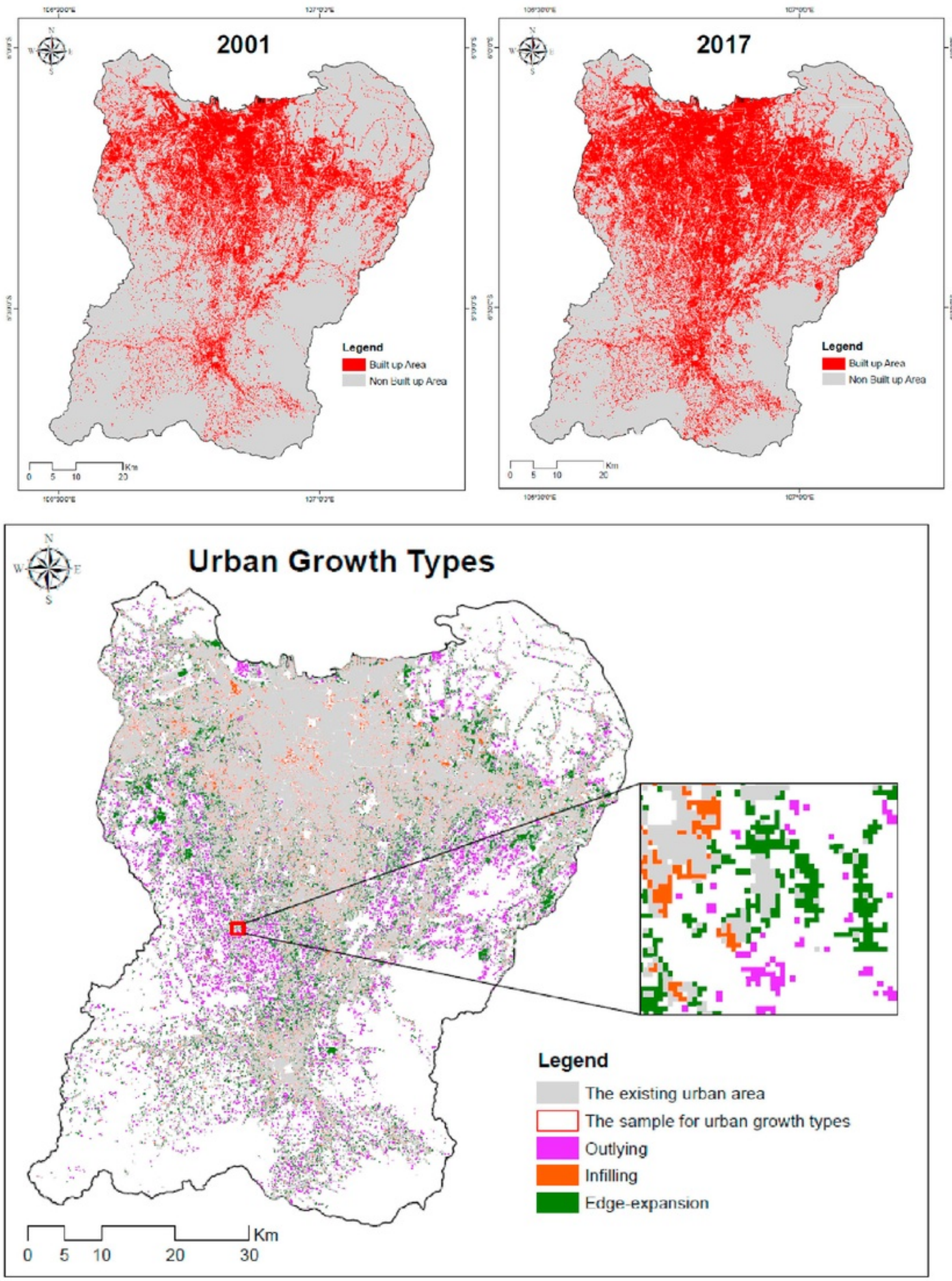

Fig. 2. (A) Urban area map in 2001; **(B)** Urban area map in 2017; **(C)** Urban growth types in 2001–2017.

Table 2
Spatial metrics employed in the assessment of the characteristics of urban growth in the study area.

No.	Metric	Abbrev	Description	Range (unit)
1	Number of Patches	NP	The number of patches of the corresponding patch type (class)	NP ≥ 1 (none)
2	Mean Patch Size	MPS	The total landscape area divided by the total number of patches	MPS > 0 (hectare)
3	Large Patch Index	LPI	The proportion of the largest patch in a given class to the entire landscape area	0 < LPI ≤ 100 (%)
4	Edge Density	ED	The sum of the lengths of all edge segments in the landscape, divided by the total landscape area	ED ≥ 0 (meters/hectare)
5	Euclidean Mean Nearest Neighbor	ENN_MN	Represents the average minimum distance between the individual patch	ENN_MN > 0 (meters)

Table 3
Summary of the dominant cities, districts and watershed from directional analysis in the study area.

Direction	Dominant districts/cities	Dominant watershed
North (N)	Jakarta	Ciliwung (downslope), Krukut, Sunter and Buaran
North-East (NE)	Northern part of Bekasi District and Bekasi City	Bekasi (downslope) and Cakung
East (E)	Southern part of Bekasi District	Bekasi (midslope)
South-East (SE)	Eastern part of Bogor District	Bekasi (upslope)
South (S)	Center part of Bogor District and Bogor City	Cisadane (upslope), Ciliwung (upslope) and Bekasi (upslope)
South-West (SW)	Western part of Bogor District	Cisadane (upslope) and Angke Pesanggrahan (upslope)
West (W)	Northern part of Bogor District and Depok City	Cisadane (midslope) and Angke Pesanggrahan (midslope)
North-West (NW)	Tangerang City, South Tangerang City and Tangerang District	Cisadane (downslope) and Angke Pesanggrahan (downslope)

rates. The Southeast (SE) region showed the lowest population and urban growth rates. Fig. 4a also display similar population growth rates in the North (N) and the Northwest (NW) regions, while the urban growth rate in the North (N) area about 50% that of the NW area.

Spatial identification to classify types of urban growth revealed that 57.04% of the urban area studied is classified as edge expansion. The infilling urban growth type represented 37.69%, while the outlying class consisted of 15.17% (Fig. 3). Careful observation of each region shows that the infilling growth type covers most areas in the North (N) region, while other regions were mostly identified as edge expansion. The edge expansion and infilling growth types occur mostly in the Northwest (NW) while the outlying growth type is prevalent in the East (E) region.

4.2. Spatial metrics analysis

According to Clarke et al. (2005), spatial metrics are used to spatially measure the heterogeneity of each patch, all patches in a class, and landscape conditions in a set of patches. In this study, we used 5 metrics to describe the characteristics of patches including the number, the size, the shape, the density, the edge, the distribution, and the diversity.

In general, the NP in the study area decreased from 2001 to 2017 (Table 4). The incorporation of patches resulting from the growth of new urban lands account for the decrease in the NP. Patch integration was indicated by a significant increase of the MPS. The increase of the LPI to over 100% suggests that the largest patch in the study area continues to expand.

In fact, a decrease in the NP was only found in the Northwest (NW), North (N) and Northeast (NE) regions, with a significant decrease in the Northwest (NW) region (Fig. 4). Moreover, the MSL and LPI values increased significantly in the Northwest (NW), North (N), and Northeast (NE) regions. The NP increased mostly in the Southwest (SW) and East (E) regions. Besides, the increases in MSL and LPI values in the region of Southwest (SW) and East (E) regions were considerably low relative to other regions.

The ED is a development indicator of urban sprawl, which displays the fragmentation of urban land. The ED value is significantly influenced by the NP, with higher ED as NP increases. In the study area, the increasing value of the ED was influenced by unevenly distributed decreases in the NP values. Fig. 4 shows that the increase in the ED values are dominant in the East (E), West (W) and Southwest (SW) regions, coinciding with a significant increases in NP values.

The change in the ENN_MN value (Table 4) demonstrated that the types and characteristics of urban growth in the study area were capable of reducing the average distance of an urban patch by approximately 9%. Furthermore, we noticed that the North (N) region displayed the lowest value of ENN_MN, with little change from 2001 to 2017. The ENN_MN values for the Southwest (SW), West (W) and East (E) regions decreased significantly. The decrease in the ENN_MN values indicated that the presence of new patches around the existing urban area.

5. Discussion

A key element in the analysis of land cover changes including the types and characteristics of urban growth using remote sensing data is the accuracy of the land cover classification. The accuracy of land cover classification is strongly influenced by the spatial and spectral resolution, the seasonal variability in vegetation cover and the soil moisture conditions (Poursanidis et al., 2015). The Landsat series of satellites provide frequently used remote sensing data used in land cover analysis including urban, peri-urban and rural areas analysis. Although Landsat imagery is qualified as providing a low-resolution image (30 m), this free image, contains a complete spectral channel (Band). The combination of spectral channels from an image generates colored images that permit users to identify and distinguish characteristics and conditions of land cover. These characteristics facilitates the detection, measurement, and analysis of changes in objects on the Earth's surface. A detailed mapping of urban land requires very high-resolution satellite images like those from Worldview, Geoeye, and Pleiades. However, the use of high-resolution satellite image data requires financial and computer resources beyond those for processing Landsat imagery. The Sentinel imagery is an alternative available for free, with a spatial resolution of 10 m.

In this study, we used the Landsat 7 ETM + imagery to produce urban land maps for 2001 because, in that year, the Landsat 8 OLI and Sentinel satellites were yet launched. The Landsat 8 OLI imagery served in producing urban land maps for 2017 because, stripping lines have affected Landsat 7 ETM + satellite imagery since 2003. The urban land map from the UI results indicate that the Landsat 8 OLI imagery generates better urban land maps than the Landsat 7 ETM + imagery. The primary classification error for urban land is the misclassification of bare land as urban land. This is consistent with research by Poursanidis et al. (2015), which shows that Landsat 8 OLI imagery produce more accurate land cover maps (pixel- and object-based classifications)

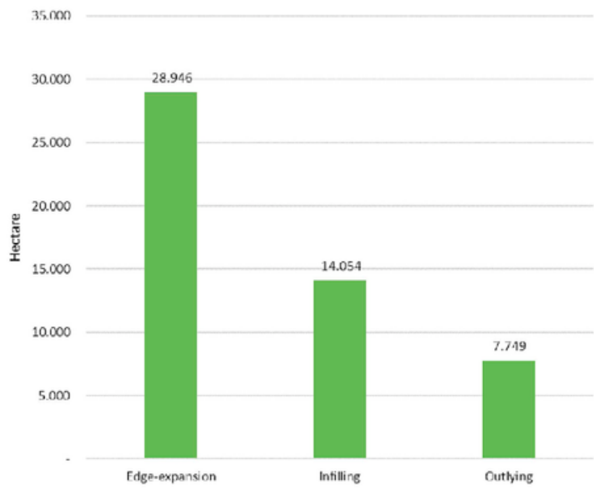

Fig. 3. The area of each urban growth type in 2001–2017.

Table 4
The Spatial metric result in the study area.

No	Metrics	2001	2017	Δ 2017–2011
1	NP	21890	21320	- 570
2	MPS (hectare)	3.72	6.19	2.48
3	LPI (%)	7.42	20.01	12.59
4	ED (meters/hectare)	47.99	63.86	15.87
5	ENN_MN (meters)	100.76	91.71	- 9.04

compared to Landsat TM. The misclassifications observed in the Landsat 8 OLI results were subordinate to those for the Landsat TM.

The similarity between the urban growth rate the population growth rate indicates a significant control of the latter on the former. The Bekasi watershed, Angke Pesanggrahan watershed, and Cisadane watersheds account for 70.41% of urban land growth. This is explained by the size and proximity of these watersheds to Jakarta's peri-urban area. The urban and populations growth dominant in the downslope regions (NW, N, NE) demonstrates a preference for residential and commercial activities near Jakarta. Consequently, the small urban growth in the North (N) region (representing the Jakarta area) was classified as infilling due to the increasing population and scarcity of land. The preference to live in Jakarta over other cities observed, confirms Jakarta remains the primary economic hub. Yet, it also indicates inadequate development of the transportation network linking Jakarta to its surrounding cities. The skyrocketing prices of land and property in Jakarta can trigger the growth of slums. This will provoke other problems including environmental and, socio-economic.

The edge expansion and infilling types dominated urban growth in the study area from 2001 to 2017. According to Schneider and Woodcock (2008) and Shi et al. (2012), most urban growth in developing countries emerges near existing urban land. The spatial metrics results revealed good characteristics of urban growth in the study area, as evidenced by low sprawl. The urban land integrated as urban patch grew along the track of the existing urban patch. The urban growth in the downslope area is characteristic of adequate planning The downslope area represented an earlier urban area in the coalescence phase.

The data generated portrays the NW region as the most organized and planned area. The population growth in the region was similar to the growth of the area. The development of Bumi Serpong Damai (BSD) in Tangerang Selatan significantly influenced the urban growth in the NW area. The city of BSD, planned for development in three phases until 2035, will be the biggest city around Jakarta. It is planned to accommodate 600,000 people on 6000 ha (Winarso et al., 2015). Analysis of age, family background, educational background, occupation and yearly income reveals most residents of BSD are young professionals working in the private sector (Leisch, 2002; Winarso and Sari, 2007; Winarso et al., 2015). This study also demonstrates that Indonesians or Chinese-Indonesians from middle to high-income families constitute most property owners in the area (Leisch, 2002; Winarso et al., 2015).

The most prominent outlying urban growth occurred in the East (E) region. Outlying is a diffusion phase at the onset of formation of a city. The urban seed formed outside the existing urban area is identified as an urban sprawl because its unexpected development (Hadi et al., 2012). The result of the spatial metrics analysis showed that the urban growth in the East (E) region is more irregular relative to other areas.

The urban growth in the East (E) region is controlled by industrial activity, especially manufacturing in the southern Bekasi Regency (Cikarang Industrial Towns & Estates). In 2017, the manufacturing contributed 78.37% of the Bekasi Regency GDRP. The Statistics Agency of the Bekasi Regency (2018) also revealed manufacturing accounted for 35.56% of the workforce. The industrial activity in this area is supported by easy access to the Jakarta-Cikampek highway, which facilitates transport to Jakarta and the International Harbor of Tanjung Priuk. The connection of the Bekasi Regency to the Jatiluhur dam provides a nearby adequate source of water. In addition to better access to the water source, (Hudalah and Firman (2012), indicate that the location of the main industrial area on land covering only three of twenty-one sub-districts in the Bekasi Regency explains an income gap among the sub-districts.

According to Abdullah (2012) rapid growth of the manufacturing industry sector can trigger urban sprawl. Urban growth is primarily driven by the residential needs of industry workers. The economic inequality as observed in the East (E) region, forces the low to middle income population to seek affordable residential areas, usually in remote areas.

Sustainable development of a region or city depends strongly on the condition of the watershed in the region. The continues growth of urban land in an urban system degrades the environmental capacity and disrupts the balance of the watershed system. The criticality level of the catchment area in the Bekasi Regency, the city of Bekasi, the Bogor regency, the city of Depok, the Tangerang regency, and the city of South Tangerang increased significantly from 2001 to 2017 (Fitriyanto and Helmi, 2018). The cities and regencies are mostly located in the NW and NE zones, which experienced the highest growth of urban land in this study. The high population and urban growth especially in Jakarta's peri-urban areas threatens food and water security. This prompted the government include the Ciliwung and the Cisadane watersheds within the 15 critical watersheds priority of Indonesia, as revealed by the National Medium-Term Development Plan (RPJMN) 2015–2019.

6. Conclusions

The urban growth phase was effectively described through classification of the types of urban growth. The study area is characterized by the edge expansion and the infilling urban growth types, and it is in the coalescence phase. The edge expansion and the infilling urban growth types are prevalent with increasing proximity to Jakarta. The increasing population and growth of infilling urban areas in Jakarta demonstrate the desire for people to reside closest to Jakarta. This desire is explained by the bad and unintegrated inter-regional transportation system.

The spatial metrics method explains the characteristics and pattern of urban growth in each area. Through the spatial metrics method, we can tell apart the urban growth pattern in the regions with edge expansion type. Urban growth in the Northwest (NW) region is more orderly relative to other regions.

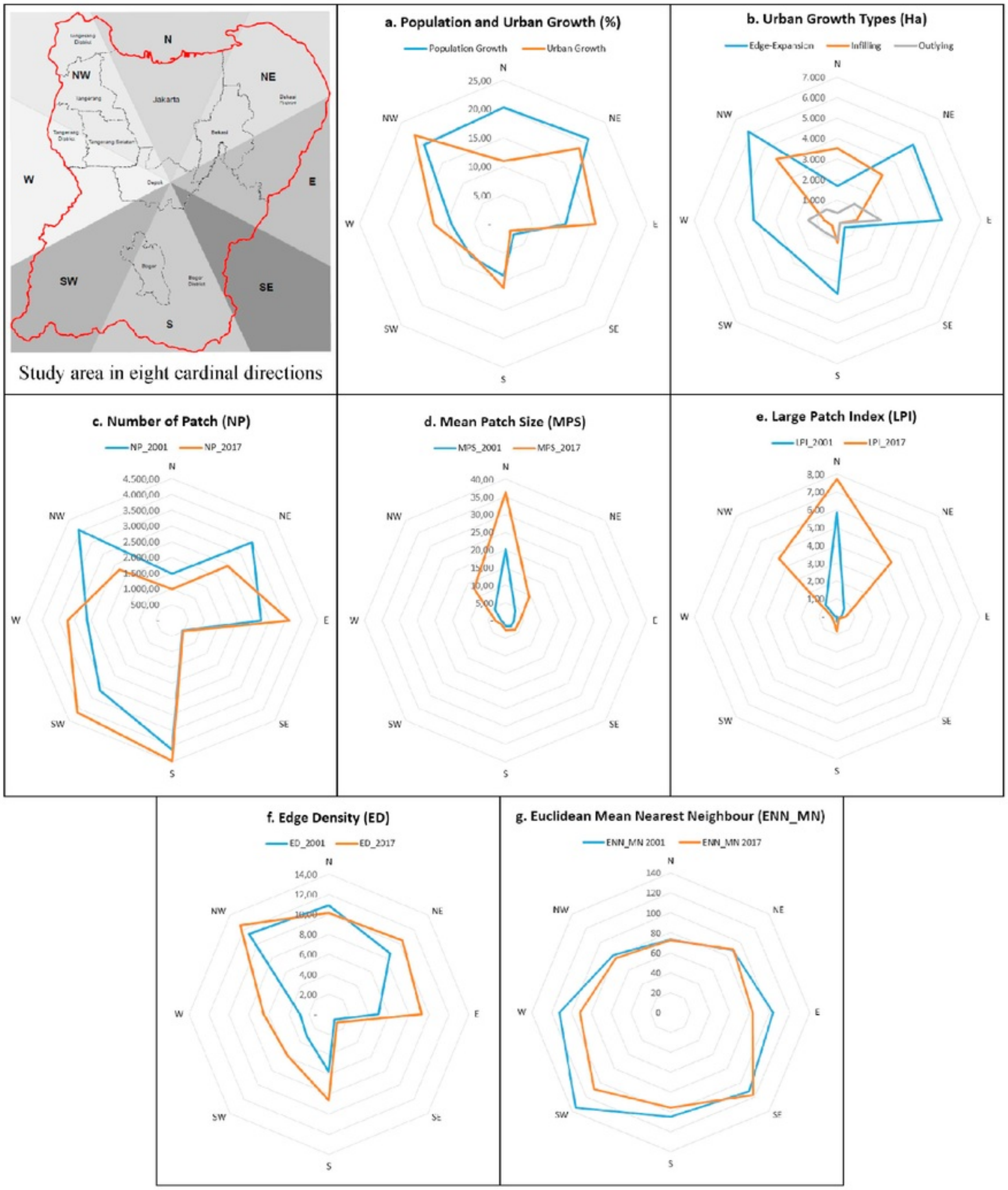

Fig. 4. Urban growth types and patterns in each direction.

The characteristics of urban growth are influenced by several factors. It is necessary to closely examine these factors and their interaction in shaping urban areas. Accurate information about the types, characteristics, and controlling factors of urban growth provide a basis for predicting urban growth and improvement of regional management plans.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.rsase.2019.04.002.

References

Abdullah, J., 2012. City competitiveness and urban sprawl: Their implications to socio-economic and cultural life in Malaysian cities. Procedia - Social and Behavioral Sciences 50 (July), 20–29. https://doi.org/10.1016/j.sbspro.2012.08.012.

Akintunde, J.A., Adzandeh, E.A., Fabiyi, O.O., 2016. Spatio-temporal pattern of urban growth in Jos Metropolis, Nigeria. Remote Sensing Applications: Society and Environment 4, 44–54. https://doi.org/10.1016/j.rsase.2016.04.003.

Ali, M., Hadi, S., Sulistyantara, B., 2016. Study on land cover change of Ciliwung downstream watershed with spatial dynamic approach. Procedia - Social and Behavioral Sciences 227 (November 2015), 52–59. https://doi.org/10.1016/j.sbspro.2016.06.042.

Barham, E., 2001. Ecological boundaries as community boundaries: The politics of watersheds. Soc. Nat. Resour. 14 (3), 181–191. https://doi.org/10.1080/08941920119376.

Bekalo, M.T., 2009. Spatial Metrics and Landsat Data for Urban Landuse Change Detection in Addis Ababa. Ethiopia 1–75.

Bhat, P.A., Shafiq, M. ul, Mir, A.A., Ahmed, P., 2017. Urban sprawl and its impact on landuse/land cover dynamics of Dehradun City, India. International Journal of Sustainable Built Environment 6 (2), 513–521. https://doi.org/10.1016/j.ijsbe.2017.10.003.

Bruegmann, R., 2005. Sprawl: a Compact History. The University of Chicago, Chicago.

Chen, J., Li, M., Liu, Y., Shen, C., Hu, W., 2010. Extract Residential Areas Automatically by New Built-Up Index. 2010 18th International Conference On Geoinformatics. Geoinformatics, vol. 2010, 40701117. https://doi.org/10.1109/GEOINFORMATICS.2010.5567823.

Clarke, K.C., Couclelis, H., Clarke, K.C., 2005. The role of spatial metrics in the analysis and modeling of urban land use change. Comput. Environ. Urban Syst. 29 (4), 369–399. https://doi.org/10.1016/j.compenvurbsys.2003.12.001.

Dahal, K.R., Benner, S., Lindquist, E., 2017. Urban hypotheses and spatiotemporal characterization of urban growth in the Treasure Valley of Idaho, USA. Appl. Geogr. 79, 11–25. https://doi.org/10.1016/j.apgeog.2016.12.002.

Dasgupta, A., Kumar, U., Ramachandra, T.V., 2010. Urban landscape analysis through spatial metrics. International Conference on Infrastructure, Sustainable Transportation and Urban Planning 1–9.

Dietzel, C., Oguz, H., Hemphill, J.J., Clarke, K.C., Gazulis, N., 2005. Diffusion and coalescence of the Houston Metropolitan Area: evidence supporting a new urban theory. Environ. Plan. Plan. Des. 32 (2), 231–246. https://doi.org/10.1068/b31148.

Duda, R., Hart, P., Stork, D., 2000. Pattern Classification, second ed. A Wiley-Interscience Publication, New York.

Fitriyanto, B.R., Helmi, M., 2018. Analysis of Land Use Changes to the Criticality Level of the Catchment Area in Eight Watersheds that Flow into Jakarta Bay, Indonesia. The 3rd International Conference on Energy, Environmental and Information System. ICENIS 2018). https://doi.org/10.1051/e3sconf/2018730 3001.

Forman, R.T.T., 1995. Land Mosaics: the Ecology of Landscapes and Regions. Cambridge University Press, Cambridge.

Han, M., Yang, X., Jiang, E., 2016. An Extreme Learning Machine based on Cellular Automata of edge detection for remote sensing images. Neurocomputing 198, 27–34. https://doi.org/10.1016/j.neucom.2015.08.121.

Hao, R., Su, W., Yu, D., 2012. Quantifying the type of urban sprawl and dynamic changes in Shenzhen. In: International Conference on Computer and Computing Technologies in Agriculture. Springer, Berlin, Heidelberg, pp. 407–415.

Helmi, M., Purwanto, Atmodjo, W., Subardjo, P., Aysira, A., 2018. Benthic diversity mapping and analysis base nn remote sensing and seascape ecology approach at parang islands, karimunjawa national park, Indonesia. Int. J. Civ. Eng. Technol. Volume 9 (11), 227–235.

Hudalah, D., Firman, T., 2012. Beyond property: industrial estates and post-suburban transformation in Jakarta Metropolitan Region. Cities 29 (1), 40–48. https://doi.org/10.1016/j.cities.2011.07.003.

Kawamura, M., Jayamanna, S., Tsujiko, Y., 1996. Relation between social and environmental conditions in Colombo Sri Lanka and the urban index estimated by satellite remote sensing data. International Archives of Photogrammetry and Remote Sensing XXXI (Part B7), 321–326 Vienna.

Lal, K., Kumar, D., Kumar, A., 2017. Spatio-temporal landscape modeling of urban growth patterns in Dhanbad Urban Agglomeration, India using geoinformatics techniques. Egyptian Journal of Remote Sensing and Space Science 20 (1), 91–102. https://doi.org/10.1016/j.ejrs.2017.01.003.

Leisch, H., 2002. Gated communities in Indonesia. Cities 19, 341e350.

Lillesand, T., Kiefer, R., 2005. Remote Sensing and Image Interpretation. John Wiley and Sons, New York.

Mathew, M.W., Adler-Golden, S.M., Berk, A., Felde, G., Anderson, G.P., Gorodetsky, D., Paswaters, S., Shippert, M., 2003. Atmospheric Correction of Spectral Imagery: Evaluation of the FLAASH Algorithm with AVIRIS Data. Spectral Sciences, Inc.

McGarigal, K., Cushman, S.A., Ene, E., 2012. FRAGSTATS v4: spatial pattern analysis program for categorical and continuous maps. Computer software program produced by the authors at the University of Massachusetts. Amherst. Accessed from: http://www.umass.edu/landeco/research/fragstats/fragstats. html.

Mosammam, H.M., Nia, J.T., Khani, H., Teymouri, A., Kazemi, M., 2017. Monitoring land use change and measuring urban sprawl based on its spatial forms: The case of Qom city. Egyptian Journal of Remote Sensing and Space Science 20 (1), 103–116. https://doi.org/10.1016/j.ejrs.2016.08.002.

Mumford, L., 1938. The Culture of Cities. Harcourt Brace Jovanorich.Inc., Orlando, Florida Harcourt Brace Jovanorich.Inc.

Poursanidis, D., Chrysoulakis, N., Mitraka, Z., 2015. International Journal of Applied Earth Observation and Geoinformation Landsat 8 vs . Landsat 5 : a comparison based on urban and peri-urban land cover mapping. Int. J. Appl. Earth Obs. Geoinf. 35, 259–269. https://doi.org/10.1016/j.jag.2014.09.010.

Projo, Danoedoro, 2012. *Pengantar penginderaan jauh digital*. Yogyakarta : C.V. Andi offset.

Reis, J.P., Silva, E.A., Pinho, P., 2016. Spatial metrics to study urban patterns in growing and shrinking cities. Urban Geogr. 37 (2), 246–271. https://doi.org/10.1080/02723638.2015.1096118.

Sajikumar, N., Remya, R.S., 2015. Impact of land cover and land use change on runoff characteristics. J. Environ. Manag. 161, 460–468. https://doi.org/10.1016/j.jenvman.2014.12.041.

Schneider, A., Woodcock, C.E., 2008. Compact, dispersed, fragmented, extensive? A comparison of urban growth in twenty-five global cities using remotely sensed data, pattern metrics and census information. Urban Stud. 45 (3), 659–692. https://doi.org/10.1177/0042098007087340.

Shi, Y., Sun, X., Zhu, X., Li, Y., Mei, L., 2012. Characterizing growth types and analyzing growth density distribution in response to urban growth patterns in peri-urban areas of Lianyungang City. Landsc. Urban Plann. 105 (4), 425–433. https://doi.org/10.1016/j.landurbplan.2012.01.017.

Statistical Agency of Bekasi Regency, 2018. Kabupaten Bekasi Dalam Angka 2018. Bekasi.

Statistical Agency of Jakarta, 2018. DKI Jakarta Dalam Angka 2018. Jakarta.

Sun, C., Wu, Z.F., Lv, Z.Q., Yao, N., Wei, J.B., 2012. Quantifying different types of urban growth and the change dynamic in Guangzhou using multi-temporal remote sensing data. Int. J. Appl. Earth Obs. Geoinf. 21 (1), 409–417. https://doi.org/10.1016/j.jag.2011.12.012.

Winarso, H., Sari, M., 2007. Transformasi sosial ekonomi masyarakat peri-urban di Sekitar pengembangan lahan skala besar: kasus Bumi Serpong Damai. Journal of Regional and City Planning 18 (1), 1e30.

Winarso, H., Hudalah, D., Firman, T., 2015. Peri-urban transformation in the Jakarta metropolitan area. Habitat Int. 49, 221–229. https://doi.org/10.1016/j.habitatint.2015.05.024.

Xu, H., 2008. A new index for delineating built-up land features in satellite imagery. Int. J. Remote Sens. 29 (14), 4269–4276. https://doi.org/10.1080/01431160802039957.

Zha, Y., Gao, J., Ni, S., 2003. Use of normalized difference built-up index in automatically mapping urban areas from TM imagery. Int. J. Remote Sens. 24 (3), 583–594. https://doi.org/10.1080/01431160304987.

9. Analyzing spatiotemporal types and patterns of urban growth in watersheds that flow into Jakarta Bay, Indonesia

ORIGINALITY REPORT

17%	%	14%	12%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Rajesh Kumar. "Flood hazard assessment of 2014 floods in Sonawari sub-district of Bandipore district (Jammu & Kashmir): An application of geoinformatics", Remote Sensing Applications: Society and Environment, 2016 Publication	1%
2	Weicheng Fei, Shuqing Zhao. "Urban land expansion in China's six megacities from 1978 to 2015", Science of The Total Environment, 2019 Publication	1%
3	Deng, J.S.. "Spatio-temporal dynamics and evolution of land use change and landscape pattern in response to rapid urbanization", Landscape and Urban Planning, 20090930 Publication	1%
4	Mojolaoluwa Toluwalase Daramola, Emmanuel Olaoluwa Eresanya, Kazeem Abiodun Ishola. "Assessment of the thermal response of variations in land surface around an urban	1%

area", Modeling Earth Systems and Environment, 2018
Publication

5	Can Bülent Karakuş. "The Impact of Land Use/Land Cover (LULC) Changes on Land Surface Temperature in Sivas City Center and Its Surroundings and Assessment of Urban Heat Island", Asia-Pacific Journal of Atmospheric Sciences, 2019 Publication	1%
6	Springer Remote Sensing/Photogrammetry, 2015. Publication	1%
7	Submitted to University of Wisconsin System Student Paper	1%
8	"Urban Development in Asia and Africa", Springer Nature, 2017 Publication	1%
9	Submitted to Federal University of Technology Student Paper	<1%
10	Terence Darlington Mushore, John Odindi, Timothy Dube, Onisimo Mutanga. "Prediction of future urban surface temperatures using medium resolution satellite data in Harare metropolitan city, Zimbabwe", Building and Environment, 2017 Publication	<1%

11	Ronggang Zhou. "Impact of Mental Rotation Strategy on Absolute Direction Judgments: Supplementing Conventional Measures with Eye Movement Data", Lecture Notes in Computer Science, 2007 Publication	<1%
12	Charles Dietzel, Hakan Oguz, Jeffery J Hemphill, Keith C Clarke, Nicholas Gazulis. "Diffusion and Coalescence of the Houston Metropolitan Area: Evidence Supporting a New Urban Theory", Environment and Planning B: Planning and Design, 2016 Publication	<1%
13	Submitted to Sheffield Hallam University Student Paper	<1%
14	Dandan Liu, Nengcheng Chen. "Satellite Monitoring of Urban Land Change in the Middle Yangtze River Basin Urban Agglomeration, China between 2000 and 2016", Remote Sensing, 2017 Publication	<1%
15	Submitted to University of Newcastle upon Tyne Student Paper	<1%
16	Casas-Prat, M., and J. P. Sierra. "Projected future wave climate in the NW Mediterranean Sea", Journal of Geophysical Research Oceans,	<1%

2013.
Publication

17	Submitted to University of Greenwich Student Paper	<1%
18	Submitted to Higher Education Commission Pakistan Student Paper	<1%
19	Submitted to 7996 Student Paper	<1%
20	Herold, M.. "The spatiotemporal form of urban growth: measurement, analysis and modeling", Remote Sensing of Environment, 20030815 Publication	<1%
21	Zhou, Kehao, Yaolin Liu, Ronghui Tan, and Yan Song. "Urban dynamics, landscape ecological security, and policy implications: A case study from the Wuhan area of central China", Cities, 2014. Publication	<1%
22	Dahal, Khila R., Shawn Benner, and Eric Lindquist. "Urban hypotheses and spatiotemporal characterization of urban growth in the Treasure Valley of Idaho, USA", Applied Geography, 2017. Publication	<1%
23	Lu, Linlin, Huadong Guo, Cuizhen Wang,	

Martino Pesaresi, and Daniele Ehrlich. "Monitoring bidecadal development of urban agglomeration with remote sensing images in the Jing-Jin-Tang area, China", Journal of Applied Remote Sensing, 2014.
Publication | <1%

---

24 X. Yu. "An integrated evaluation of landscape change using remote sensing and landscape metrics: a case study of Panyu, Guangzhou", International Journal of Remote Sensing, 3/1/2006
Publication | <1%

---

25 Submitted to University of Brighton
Student Paper | <1%

---

26 "International Perspectives on Suburbanization", Springer Nature, 2011
Publication | <1%

---

27 Submitted to RMIT University
Student Paper | <1%

---

28 Zhe Feng, Jiansheng Wu, Yang Gao, Jian Peng. "Environmental Policy Simulation and Assessment under Rapid Urbanization: Case Study of Essential Area Policy in Shenzhen, China", Journal of Urban Planning and Development, 2015
Publication | <1%

Fangyan Cheng, Shiliang Liu, Xiaoyun Hou,

29	Yueqiu Zhang, Shikui Dong. "Response of bioenergy landscape patterns and the provision of biodiversity ecosystem services associated with land-use changes in Jinghong County, Southwest China", Landscape Ecology, 2018 Publication	<1%
30	Haryo Winarso, Delik Hudalah, Tommy Firman. "Peri-urban transformation in the Jakarta metropolitan area", Habitat International, 2015 Publication	<1%
31	Submitted to University of Oklahoma Student Paper	<1%
32	Zhang, Caiyun, Donna Selch, Zhixiao Xie, Charles Roberts, Hannah Cooper, and Ge Chen. "Object-based benthic habitat mapping in the Florida Keys from hyperspectral imagery", Estuarine Coastal and Shelf Science, 2013. Publication	<1%
33	Chao Zhang, Shuai Zhong, Xue Wang, Lei Shen, Litao Liu, Yujie Liu. "Land Use Change in Coastal Cities during the Rapid Urbanization Period from 1990 to 2016: A Case Study in Ningbo City, China", Sustainability, 2019 Publication	<1%
34	Riantini Virtriana, Irawan Sumarto, Albertus Deliar, Agung Budi Harto, Moh. Taufik, Udjianna S Pasaribu. "The integration method of cellular	<1%

automata(CA) J-Markov chain(MC), West Java's Northern part characteristics for land cover change prediction study", 2014 2nd International Conference on Technology, Informatics, Management, Engineering & Environment, 2014
Publication

35 Sadeq Dezhkam, Bahman Jabbarian Amiri, Ali Asghar Darvishsefat, Yousef Sakieh. "Simulating the urban growth dimensions and scenario prediction through sleuth model: a case study of Rasht County, Guilan, Iran", GeoJournal, 2013 <1%
Publication

36 Submitted to The University of Manchester <1%
Student Paper

37 Submitted to University of Queensland <1%
Student Paper

38 Limin Jiao, Jiafeng Liu, Gang Xu, Ting Dong, Yanyan Gu, Boen Zhang, Yaolin Liu, Xiaoping Liu. "Proximity Expansion Index: An improved approach to characterize evolution process of urban expansion", Computers, Environment and Urban Systems, 2018 <1%
Publication

39 Pribadi, Didit Okta, and Stephan Pauleit. "Peri-urban agriculture in Jabodetabek Metropolitan Area and its relationship with the urban <1%

socioeconomic system", Land Use Policy, 2016.
Publication

40 Submitted to Universitas Muhammadiyah Surakarta <1%
Student Paper

41 I Rahmaningtyas, A Y S Rahayu. "Collaborative Governance in Providing Facilities of Sungai Bambu Child Friendly Integrated Public Space, North Jakarta City", IOP Conference Series: Earth and Environmental Science, 2019 <1%
Publication

42 Yuguo Qian, Yingyun Chen, Cong Lin, Weimin Wang, Weiqi Zhou. "Revealing patterns of greenspace in urban areas resulting from three urban growth types", Physics and Chemistry of the Earth, Parts A/B/C, 2019 <1%
Publication

43 Andri N. R. Mardiah, Jon C. Lovett, Nukila Evanty. "Chapter 3 Toward Integrated and Inclusive Disaster Risk Reduction in Indonesia: Review of Regulatory Frameworks and Institutional Networks", Springer Science and Business Media LLC, 2017 <1%
Publication

44 Submitted to University of Cambridge <1%
Student Paper

Jiajia Zhao, Chao Zhu, Shuqing Zhao.

45	"Comparing the Spatiotemporal Dynamics of Urbanization in Moderately Developed Chinese Cities over the Past Three Decades: Case of Nanjing and Xi'an", Journal of Urban Planning and Development, 2015 Publication	<1 %
46	Hayati Sari Hasibuan, Tresna P. Soemardi, Raldi Koestoer, Setyo Moersidik. "The Role of Transit Oriented Development in Constructing Urban Environment Sustainability, the Case of Jabodetabek, Indonesia", Procedia Environmental Sciences, 2014 Publication	<1 %
47	H. Xu. "A new index for delineating built-up land features in satellite imagery", International Journal of Remote Sensing, 2008 Publication	<1 %
48	Submitted to University College London Student Paper	<1 %
49	Joko Widodo, Arie Herlambang, Albertus Sulaiman, Pakhrur Razi et al. "Land subsidence rate analysis of Jakarta Metropolitan Region based on D-InSAR processing of Sentinel data C-Band frequency", Journal of Physics: Conference Series, 2019 Publication	<1 %
50	Liu, Xiaoping, Lei Ma, Xia Li, Bin Ai, Shaoying	

Li, and Zhijian He. "Simulating urban growth by integrating landscape expansion index (LEI) and cellular automata", International Journal of Geographical Information Science, 2014.
Publication | <1%

51 Submitted to University of Western Australia
Student Paper | <1%

52 Poursanidis, Dimitris, Nektarios Chrysoulakis, and Zina Mitraka. "Landsat 8 vs. Landsat 5: A comparison based on urban and peri-urban land cover mapping", International Journal of Applied Earth Observation and Geoinformation, 2015.
Publication | <1%

53 Tauseef Ahmad, Arvind Chandra Pandey, Amit Kumar. "Evaluating urban growth and its implication on flood hazard and vulnerability in Srinagar city, Kashmir Valley, using geoinformatics", Arabian Journal of Geosciences, 2019
Publication | <1%

54 Submitted to The Hong Kong Polytechnic University
Student Paper | <1%

55 Submitted to Mount Kenya University
Student Paper | <1%

56 Wenyuan Qu, Shuqing Zhao, Yan Sun. "Spatiotemporal patterns of urbanization over | <1%

the past three decades: a comparison between two large cities in Southwest China", Urban Ecosystems, 2014
Publication

---

57 Submitted to Rutgers University, New Brunswick <1%
Student Paper

---

58 Weizhong Su, Chaolin Gu, Guishan Yang, Shuang Chen, Feng Zhen. "Measuring the impact of urban sprawl on natural landscape pattern of the Western Taihu Lake watershed, China", Landscape and Urban Planning, 2010 <1%
Publication

---

59 Estoque, Ronald C., and Yuji Murayama. "Classification and change detection of built-up lands from Landsat-7 ETM+ and Landsat-8 OLI/TIRS imageries: A comparative assessment of various spectral indices", Ecological Indicators, 2015. <1%
Publication

---

60 Submitted to University of Southampton <1%
Student Paper

---

61 Submitted to International Islamic University Malaysia <1%
Student Paper

Exclude quotes	On	Exclude matches	Off
Exclude bibliography	On		