Urban expansion analysis through Remote Sensing and GIS in Semarang-Indonesia

L Indrawati1, S H Murti2*, R Rachmawati2, and A Kurniawan3

1 Doctoral Program, Geography Faculty, Universitas Gadjah Mada, Yogyakarta, Indonesia
2 Geography Faculty, Universitas Gadjah Mada, Yogyakarta, Indonesia
3 Student of Geographyc Information System Program, Vocational Collage, Universitas Gadjah Mada, Yogyakarta, Indonesia

*sigit@geo.ugm.ac.id

Abstract. Urban areas and their expansion are important roles for the analysis of the urban ecological status, indicators for global ecological health, and sustainable development. Although urban expansion can improve the living conditions of the residents, it will also lead to various urban environmental and ecological issues. Semarang City is the center of a functioning metropolitan city of Kedungsepur (Kendal, Demak, Ungaran, Semarang Regency, Salatiga City, Semarang City and Purwodadi, Grobogan Regency) so that the development of various sectors in the Semarang City region shows a positive increase. This study aims to measure urban expansion and analyze its spatial patterns from 2005 to 2015 using remote sensing and GIS. The analysis method to measure urban expansion and developing patterns uses the urban expansion intensity index and local Moran’s I, and quantification the typology of urban expansion. The results showed that the annual growth rate of urban expansion in Semarang city increased in the last decade, which was 2.7 km²/year (2005-2011) to 5.8 km²/year (2011-2015). The intensity of urban expansion is more dominated by low intensity followed by very rapid, moderate and rapid intensity. The results of Local Moran’s I analysis also show the formation of urban growth clusters out of the city center that leads to the south. Between 2005 and 2015 the type of urban expansion was dominated by the type of edge expansion.

1. Introduction
Urban is a location-based characteristic that combines elements of population size and population density, social and economic, and the transformation of the natural environment and agriculture into a built environment [1]. Urban areas have the characteristics of high-density impervious surfaces that affect the structure and function of urban systems, which are considered as the main indicators of urban environmental conditions. Urban expansion is a form of urbanization and takes place in different ways such as in the form of increased building densities in existing areas, through filling in the remaining open space in areas that have been built, or through new developments in areas previously used for non-urban areas [2]. Even though urban areas only cover a small area on the surface of the earth, the effects of rapid urban expansion have significantly changed the natural landscape and created substantial impacts on the environment, ecosystem and social [3]; [4]; [5]. Rapid urban expansion is driving land-use conversion which is a major driving factor in changing landscapes so that it can lead to wider environmental problems. The impact is not only on the urban areas themselves but also transcend the city’s physical boundaries, especially in large cities and metropolitan areas around the world.

Remote sensing data has been used extensively for urban expansion studies. This data is available with detailed spatial resolution and adequate temporal frequencies for urban morphology and its changes. In particular, information about the history of urban development can be revealed by multi temporal remote sensing data which is important for measuring the urban development process. Among the various remote sensing data available, Landsat imagery including MSS, TM / ETM + and
OLI is one of the most widely used data to study urban expansion [6]. Integrating remote sensing data with the urban analysis landscape is very useful for understanding the spatiotemporal patterns of urban expansion [7]. Remote sensing can also help reveal the spatial distribution of newly built areas, spatiotemporal patterns, and changes over time through indices such as urban expansion intensity [8]; [9] and local Moran’s I [10];[8]. In addition, the integration between remote sensing data and the application of Geographic Information System (GIS) technology provides an alternative way of quickly assessing urban dynamics and development so that timely action can be taken [11].

One type of city that is very important in the urban system is a metropolitan urban area whose territory includes several districts and cities. This is because the area generally acts as the national capital, provincial capital, and center for economic activities that are national or strategic in nature. Semarang City is the capital of Central Java Province, Indonesia, which is incorporated in the Semarang megapolitan area called the Kedungsepur metropolitan (Kendal, Demak, Ungaran, Semarang Regency, Salatiga City, Semarang City, and Purwodadi, Grobogan Regency). Based on the calculation of population projections in 2019, the population of Semarang City is 1,786,114 people with population growth from 2015 to 2018 of 4.99% [12]. As the functional center of the Kedungsepur metropolitan, Semarang City is certainly experiencing rapid development, so it is an ideal candidate for the current research aiming to examine the urban expansion. The purpose of this study is to measure urban expansion and analyze its spatial patterns from 2005 to 2015 using remote sensing and GIS.

2. Material and Methods

2.1. Study areas

Semarang is the capital of Central Java province, located on the north coast of the island of Java, Indonesia. The geographical location of Semarang City is on the North 6° 50” S which borders the Java Sea, the South is at 7° 10” S which borders Semarang Regency, the West is at 109° 50” E which borders Kendal Regency, and the next East is at 110° 35” E bordering Demak Regency (Figure 1).

![Figure 1. The location of the study area](image)

Topographically, Semarang consists of two main landscapes, namely lowlands and coastal areas in the north and hilly areas in the south. The northern part is the center of the city, where there are government centers, ports, airports, train stations, trade, industry, ponds, and agriculture. The topography of this part is relatively flat with slopes ranging from 0° to 2°, and height between 0 to 3.5 m. This part is also an old city that has a higher population density and there are more industrial and business areas than to the south. The southern part includes slopes up to 45° and altitudes up to about 350 m above sea level. This area is developing quite rapidly with the presence of one of the state
universities and as an alternative place to residing that is free from flooding. The development of settlements in this area is also equipped with various public facilities such as shopping centers and hospitals. Of land use to the south consists of housing, offices, retail, public use, and open space areas (plantations and agriculture) including Jatibarang reservoir. The development of the city is increasingly moving to the upper regions. This trend threatens upstream areas that function as conservation areas.

2.2. Data source and image pre-processing
The materials used in this study are Landsat-7 ETM + imagery (2005), Landsat 5 TM (2011) and Landsat-8 OLI (2015) obtained by downloading for free via the web https://earthexplorer.usgs.gov/ in June 2019, BIG Single Base Map and BPS statistic data. Before image processing, radiometric corrections and geometric corrections are performed. Geometric corrections are mainly carried out between multi temporal images in each area of research interest. Geometric correction is performed using the image to image method between multi temporal images. The RMS error value in this geometric correction must be as small as possible, in this case less than 0.5 of the pixel size to avoid the uncertainty of detecting changes in land cover due to errors in geometric correction in multi temporal images.

2.3. Mapping of land cover
The land cover map is used to obtain information on urban and non-urban areas. The initial step is to create a 2015 land cover map using a combination of object-based classification and visual interpretation; this map is then used as a reference map to produce land cover maps in 2011 and 2005. In addition, extensive manual editing is done to improve the visual classification using references from pan-sharpening of Landsat-7 ETM + and Landsat-8 OLI images.

Finally, the map of land cover is validated based on high spatial resolution images and checked by ground truth. The validation calculation uses the method proposed by Foody (2002)[13] and finds an accuracy rate of 93.7% (Overall accuracy).

2.4. Data analysis
Urban expansion in the period 2005-2011 and 2011-2015 was made based on land cover maps for 2005, 2011 and 2015 through overlay analysis. Urban expansion analysis uses the following methods:

2.4.1. Urban Expansion Intensity Index (UEII). The Urban Expansion Intensity Index (UEII) is a proportion of the increase in new urban areas to their total area. This index is produced to evaluate the spatial distribution of city expansion in different periods. It is calculated as follows:

\[
UEII_{t,t+n} = \frac{UA_{t+n} - UA_t}{UA_t} \times 100
\]

Where is UEII_{t,t+n} is the intensity of urban expansion for spatial units i over the time span t and t+n; UA_{t+n} and UA_t represents the urban land area of the spatial unit i at that time t+n and t; TA_i is the total area of the spatial unit i. The spatial unit in this study is a grid index of 0.25 km x 0.25 km, and UEII at the spatial unit level is divided into five classes with special standards 0, 0-25%, 25-50%, 50-75%, 75-100%, which corresponds to the intensity of urban expansion, respectively, zero, low, moderate, rapid and very rapid.

2.4.2. Local Moran’s I Index. Local Moran’s I measure the level of spatial autocorrelation at each specific location [10]. This index is good for identifying local spatial cluster patterns and spatial outliers [14]. Local Moran’s I is useful in detecting urban sprawl directly connected to the downtown area (mono-functional) and satellite cities or new cities that are planned to be separate from major city centers [10]. Local Moran’s I Index can be stated as:

\[
I_i = \frac{z_i - \bar{z}}{s^2} \sum_{j=1}^{n} W_{ij}(e_j - \bar{z})
\]
Where z is the mean value of z with the number of samples n; z_i is the value of the variable at location i; z_j is the value at another location (where j ≠ i); \sigma^2 is the z variant; and W_{ij} is the weight of the distance between z_i and z_j, which can be defined as the inverse of distance. W_{ij} weight can also be determined using a distance band: samples in the distance band are given the same weight, while outside the distance band are given a weight of 0.

2.4.3. Urban Expansion Type. Quantification of urban growth is very important to help land-use planners better analyze the characteristics of urban sprawl on a local to regional scale. Urban development consists of four types: spatial leapfrogging/ outlying, edge-expansion, infilling and strip by following the detailed methods in Xu et al. (2007)[15]. Specifically, the equation below (Eq.3) is used to classify new land development patches:

\[
R_i = \frac{pc}{pi} 
\]

Where, \(R_i\) is the ratio for a newly developing patch i, \(pc\) is the shared boundary between a new development patch and a previous development patch, and \(pi\) is the total perimeter of patch i. R values range between 0 and 1. Simple heuristic rules are applied to categorize patches into four urban expansion typologies namely: If \(Ri > 0.5\), then Patch i == infill; if \(Ri <= 0.5\), then Patch i == edge-expansion; if \(Ri == 0\) and Patch i is not close to the main road, then Patch i == outlying; and if \(Ri == 0\) and Patch i is next to the main road, then Patch i == strip. If the R-value is more than 50%, most of the newly developed patches are surrounded by existing urban patches and are therefore considered as infill development.

Quantification of urban expansion typology uses codes that are run with Python in ArcGis 10.2 software. The spatial data needed in this calculation is a map of urban settlements in 2005, 2011 and 2015, and a road network map. This quantification process is quite long because the calculation is done on each patch (polygon) of new settlements, the more new patches the longer the calculation process.

2.4.4. Annual urban growth rate. To evaluate the speed of urban expansion of Semarang City in all stages, the annual urban growth rate (\(AGR_a\)) (Eq.4) and the standard annual urban growth rate (\(AGR\%)\) (Eq.5) were calculated. This annual growth directly measures the annual change in urban areas, this annual growth rate eliminates the effect of urban size and is more suitable for comparison of urban expansion for different cities in the same period. It is calculated as follows:

\[
AGR_a = \frac{A_{end} - A_{start}}{d} 
\]

\[
AGR(%) = 100\% \times \left(\frac{A_{end}}{A_{start}}\right)^{1/d} - 1
\]

Where \(AGR_a\) (km\(^2\)/year) and \(AGR\%)\ are the annual growth and annual growth rates of the urban area, \(A_{start}\) and \(A_{end}\) are the respective urban areas in the start and the end periods, and \(d\) is the study time span for a certain time.

3. Results and Discussion

3.1. Change of temporal urban area

Over the past 10 years, the City of Semarang has experienced significant urban expansion (Figure 2 and Table 1). Urban area expanded from 169.18 km\(^2\) to 208.16 km\(^2\) from 2005 to 2011, with a growth rate of 2.7 km\(^2\)/year from 2005 to 2011 and 5.8 km\(^2\)/year from 2011 to 2015. Meanwhile, the speed of growth from 2005 until 2011 which was lower at 1.51% than to the growth rate from 2011 to 2015 which was 3.00%.

The results showed that for a decade, the city of Semarang had experienced a process of rapid urban expansion. The speed of urban expansion in the city of Semarang has almost doubled from the period 2005-2011 to 2011-2015 (Figure 2).
Table 1. Annual urban growth rate in Semarang City

| Period       | Annual growth rate in area (km²/year) | Standardized annual growth rate (%) |
|--------------|--------------------------------------|------------------------------------|
| 2005-2011    | 2.7                                  | 1.51                               |
| 2011-2015    | 5.8                                  | 3.00                               |

Source: analysis

Figure 2. Urban expansion in Semarang City

3.2. Spatial and temporal distribution of UEII and Local Moran’s I

For Semarang City, urban expansion in the period of 2005 to 2011 was less intensive than in the period of 2011 to 2015 (Figure 3). The intensity of urban expansion in both periods was dominated by low classes, followed by very rapid, moderate and finally rapid classes (Table 2). The distribution of the intensity of urban expansion in all classes mostly headed south of Semarang except in the period 2005 to 2011 there was a small portion that led east of Semarang (Figure 3).

Table 2. Area of urban expansion intensity index class

| Period       | Class of urban expansion intensity index (Km²) |
|--------------|-----------------------------------------------|
|              | Zero   | Low    | Moderate | Rapid   | Very Rapid |
| 2005-2011    | 162.98 | 6.10   | 3.57     | 3.60    | 6.02       |
| 2011-2015    | 154.86 | 25.69  | 7.72     | 5.77    | 13.30      |

Source: analysis

In local moran's calculations, only a statistically significant grid (p <0.05) is presented on the map (Figure 4), i.e. High High represent urban agglomeration, Low High indicates that the urban grid area is lower than its neighbors, and High Low shows isolated urban areas. According to the results, there are new growth centers based on urban expansion. The cluster is mainly leading to the south of the city. One of the new centers of rapid growth is in Tembalang sub-district. The main driver of regional growth is the existence of the Diponegoro University integrated campus. The impact of the existence of this campus is growing in various sectors including trade and services, housing, public infrastructure and access to transportation.
Figure 3. Urban expansion intensity in Semarang City

3.3. Characterizing the urban expansion types of built-up areas

The temporal-spatial pattern of urban expansion in the study area varies. The contribution of each urban development typology in the two periods is illustrated in Figure 5. During the entire research period, edge expansion was the dominant type of growth, namely 40.1% in the period 2005 to 2011 and 61.36% in the period 2011 to 2015, and the type of strip growth accounted for the smallest proportion (Table 3). In the period 2005 to 2011 outlying growth types have a greater area than the period from 2011 to 2015. This explains that the typology of urban expansion in small cities has more potential to develop into the outlying type whereas large cities will tend to grow into edge expansion type. Outlying types are generally the dominant types in the early stages of urban expansion, while the edge-expansion type dominates in the stages of rapid expansion, and infilling becomes the main urban expansion type at a stable stage [16].

Figure 4. Spatiotemporal distribution of local Moran’s I in Semarang

When a city is in the initial stages of being formed, many new cities are built, resulting in many traces of the leap. After the city developed, the city will experience rapid expansion, patch outlying/leapfrogging that was originally formed will experience an edge expansion that eventually joins with the others and become a broader type of edge expansion. As a result, for larger cities it will be negatively correlated with leapfrogging/outlying type, and it has a relatively positive correlation on edge-expansion type.
Table 3. Area and proportion in terms of four typologies of growth in Semarang (unit: km²)

| Period          | Edge-expansion | Infilling | Outlying | Strip |
|-----------------|----------------|-----------|----------|-------|
| 2005-2011       | 5.41           | 5.35      | 2.07     | 0.66  |
|                 | 40.10%         | 39.68%    | 15.32%   | 4.91% |
| 2011-2015       | 15.65          | 6.29      | 1.80     | 1.77  |
|                 | 61.36%         | 24.65%    | 7.06%    | 6.93% |

Source: analysis

3.4. Discussion

This research examines urban expansion mainly using remote sensing and GIS methods. In this study, to evaluate urban expansion and the patterns that develop in the city of Semarang, several analyzes of urban expansion were followed, namely, annual urban growth rates, UEII, local Moran’s I, and types of urban expansion. The results showed that the city of Semarang developed quite rapidly and mainly headed south of the city. Many new clusters appear and then develop into new cities, for example in the Tembalang sub-district. The construction of new industrial areas in the city of Semarang also contributed to urban expansion and the emergence of new urban growth centers, such as the Bukit Semarang Baru (BSB) industrial area in the Mijen sub-district and also the construction of satellite cities around the area.

Urban expansion, as the most striking form of land use/land cover change [17], is an irreversible process in which natural and semi-natural systems turn into impervious surfaces. As the increasing urban expansion, impervious artificial surfaces rise very impressively, which modifies urban microclimates, including increases in land surface temperature, resulting in urban heat islands (UHI) [18]. The urban areas have a positive exponential relationship with the land surface temperature [19]. In Semarang city, this urban expansion has increased impervious surfaces and reduced the land cover of water bodies, sparse vegetation, and dense vegetation resulting in an increase in land surface temperature in Semarang City [20]. The change of non-urban areas into urban areas also could have an impact on the value of surface runoff coefficient, if the surface runoff coefficient value is bad, then this has the potential for flooding [21]. Non-urban land which was previously in the form of rice fields, dryland agriculture, and plantations have turned into built-up land especially for District of Tembalang, Banyumanik, Gunungpati, and Mijen [22]. Urban expansion tends to occur at the expense of valuable agricultural land [23]. This will also affect food security because urban expansion has a significant negative impact on food security at the country level [24].

Concerning the four types of urban land expansion, namely, contents, edge expansion, outlying growth, and strips, the findings on Semarang expansion types improve our knowledge of the dominant types of urban expansion in Semarang. For example the outlying type, this type mainly impacts the
reduction of agricultural land which is followed by a decrease in agricultural productivity [25]. This type of urban expansion is also more difficult in terms of the arrangement.

The development of urban population activities led to a shift in activity to the suburbs. The availability of land in suburban areas has resulted in this area developing rapidly, especially as residential land. The growth of population in the city of Semarang which averaged 1.28% between 2005 and 2015 [26] also became the cause of increased space needs. Land changes to support urban development and the demands of urban populations themselves encourage other types of environmental change [27]. Because of the limited availability of land in urban areas, it is not surprising that there has been a shift to the suburbs and the demand for land for housing has increased in the suburbs.

Analysis of the spatiotemporal characteristics of urban expansion is a prerequisite for identifying the process of urban expansion, exploiting its driving mechanisms, simulating and predicting future expansion trends, and revealing the effect of city expansion on ecology and the environment [28]. Biophysical factors and socioeconomic factors are the two main categories as the driving force of urban expansion obtained through the analysis of remote sensing data [29], which are further divided into several sub-categories for specific cases, which mainly include topology, rainfall, demographics, natural resources, soil quality, industrial structure, economic growth, market transition, tourism, infrastructure, and policy [30].

4. Conclusions

Urban expansion has become one of the main impacts of humans on the environment. This study detects and compares the spatial patterns of urban expansion in the Semarang city area from 2005 to 2015 using remote sensing and GIS. Multi-temporal remote sensing has become an important data-gathering tool for analyzing these changes. The results showed that the annual growth rate of urban expansion in Semarang city increased in the last decade, which was 2.7 km²/year (2005-2011) to 5.8 km²/year (2011-2015). The intensity of urban expansion is more dominated by low intensity followed by very rapid, moderate and rapid intensity. The results of Local Moran's I analysis also show the formation of urban growth clusters out of the city center that leads to the south. The trend of the type of urban expansion that was formed during that all periods are dominated by the type of edge expansion. With the acceleration of city expansion, the Semarang local government has a big challenge in terms of management between urban expansion and environmental protection.

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