Effect of Urban Expansion Intensity on Urban Ecological Status Utilizing Remote Sensing and GIS: A Study of Semarang-Indonesia

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Abstract. The rapid urban expansion will drive land-use conversion and cause substantial environmental and ecological impacts. The ability of remote sensing to record spatial and temporal data on the land surface with complete coverage has been proven effective for recognizing spatiotemporal changes in the regional eco-environment quickly. This study utilized Landsat TM / ETM + and Landsat-8 OLI remote sensing data to assess the effect of urban expansion intensity on the urban ecological status with the study area in Semarang, Indonesia. The method to measure urban expansion uses the urban expansion intensity index and to assess the urban ecological status using an integrated ecological index (IEI). The IEI generated from four parameters which include the degree of greenness (i.e. the soil adjusted vegetation index, SAVI), the moisture degree (i.e. the normalized difference moisture index, NDMI), dryness degree (i.e. the normalized difference soil index, NDSI) and built-up aggregation degree (i.e. the normalized difference built-up index, NDBI). Principal component analysis (PCA) is used to compress the four indicators to construct the index of ecological status and Pearson correlation analysis was used to determine the effect of urban expansion intensity on urban ecological status. The result showed that the urban land area increased by 38.98 km2 with an average expansion area of 3.9 km2 y-1 from 2005 to 2015. The index of urban expansion intensity during 2011-2015 increased about 2.1 times from 2005-2011. The pattern of deteriorating urban ecological status of the city of Semarang spreading towards the west, south, southeast, and east. The lowest integrated ecological index is in the central and northern parts of the city of Semarang. The extent of good and excellent urban ecological status continues to decline in a decade, on the contrary, the urban ecological status of poor and extremely poor increased. The negative linear relationship of the index of urban expansion intensity and urban ecological status shows that the intensity of urban expansion influences the urban ecological status in Semarang city.

1. Introduction
The urban expansion causes impressive changes to the surrounding area and its processes related to biophysical and ecological processes [1]. As long as the urban population continues to increase accompanied by economic growth, the urban physical area will continue to grow rapidly. Urban expansion can occur in the form of increased building density in existing areas, through filling in the remaining open space in the area that has been built, or through new developments in areas that were
previously used for non-urban areas [2]. However, urban expansion has a contradictory effect, one side improves the living conditions of the population but also raises various environmental and ecological urban problems [3], including modifying the urban microclimate, eliminating and fragmenting native habitats, and produce anthropogenic pollutants [4], and also includes that irreversible change of land use/land cover [5], etc. Urbanization not only has a local environmental impact but also makes a large ecological footprint beyond, which is felt throughout the world, so the big challenge for sustainability on a planetary scale is caused by meeting two global trends: transition to increasing urbanization of the world and changes in the global environment [6]. However urban expansion will affect the earth's natural system and the urban ecological environment which will further affect the sustainability of the city. Therefore, examining the effect of the intensity of urban expansion on the urban ecological status scientifically is very important.

To understand complex environmental problems can be done by examining environmental problems from various causes, this is to evaluate ecological conditions and their changes so that they can maintain their urban ecological integrity [7]. Fortunately, advances in remote sensing (RS) technology and geographic information systems (GIS) have helped ecologists to accelerate the identification of spatiotemporal changes in the environment including explicit spatial monitoring for urban expansion [8][9]. Remote sensing has the advantage of providing consistent data for broad areas of spatial observation with its capability in an expressly way, fast, and cyclical monitoring. However, the use of remote sensing data also has weaknesses due to uncertainties resulting from human interference and spatial heterogeneity [10].

Semarang is one of the metropolitan cities in Indonesia, which is also the capital of the province of Central Java, which is also located on the north coast of the island of Java (Figure 1). Based on the registration in 2013, the population in Semarang was 1.572.105 with a growth rate of 1.3% in 2005-2015, during this period, population density tended to increase along with population increase. Meanwhile, the distribution in each sub-district is also not evenly distributed, which is, South Semarang Sub-district is the most densely populated area, while Mijen Sub-district is the rare [11]. Semarang is an industrial, commercial and service city. The development of the industrial area will have a positive impact, namely an increase in the economic level of society and a negative impact on the occurrence of pollution such as smoke, dust, black water and stink that can cause disease. The natural physical condition of the city of Semarang is also very unique, from the hills to the coastal plains, which naturally also has limitations in the form of potential disasters. Potential geological disasters such as faults and landslides prone. Semarang deals with various physical challenges due to its geography as a coastal city, such as tidal flooding, erosion, land subsidence and rising sea levels [12][13], which threatens the lowlands of Semarang. The city of Semarang has experienced an urban expansion of more than 70% and a decrease in the canopy of more than 35% which results in an increase in the average surface temperature of around 2-5°C between 1998 and 2018 [14]. As a result of this rise in temperature, environmental criticism has been detected in the center of the city, which is the northern part of Semarang [15]. Concurrently, development in the hilly upper Semarang has led to a decrease in vegetation coverage in the upstream area, which severely increases vulnerability to landslides, water shortages, and floods [16]. These pressures can disrupt the environment and be a challenge for the sustainability of the city of Semarang.

In this study, Semarang City as the centre of the Semarang Metropolitan Region (SMR) was chosen to study the impact of expanding urbanization on the status of urban ecology. Urban expansion analysis uses the urban expansion intensity index and annual urban growth. While for the analysis of urban ecological status using an integrated ecological index (IEI), this IEI is useful in prediction urban ecological status precisely [17]. IEI was built from four indicators representing the degree of greenness (i.e. SAVI), the moisture degree (i.e. NDMI), dryness degree (i.e. NDSI) and built-up aggregation degree (i.e. NDBI). Each of these indicators is closely related to the type of land cover and biophysical descriptors reflect the urban ecological environment. Changes in surface biophysical conditions due to urbanization that has modified natural landscapes into anthropogenic surfaces, thus changing land cover properties [17]. Integration of these indicators can realize rapid monitoring and evaluation of the regional ecological environment.
The purpose of this study is to reveal the dynamic changes and spatial characteristics of the intensity of urban expansion and the status of urban ecology in 2005 to 2015 and determine the effect of the intensity of urban expansion on urban ecological status.

Figure 1. Semarang City research area

2. Material and Methods

2.1. Data source and image pre-processing

This study uses multi-temporal remote sensing data recorded within a period of 10 years. Remote sensing images obtained from Landsat 5, Landsat-7 ETM + and Landsat-8 OLI for each recording date are listed in Table 1. Path / Row images for the entire study area, respectively, 119/065. Due to the lack of cloud-free satellite imagery in the Landsat archive for the year corresponding to the study area, the recording month varies for each year of observation but is still attempted in the same season. In this study selected images recorded in the dry season.

Table 1. Source of Landsat image data.

| Year | Path/Row | Acquisition Date |
|------|----------|------------------|
| 2005 | Landsat 7 ETM+ | 120/065 | 2005.08.29 |
| 2011 | Landsat 5 TM | 120/065 | 2011.06.19 |
| 2015 | Landsat-8 OLI | 120/065 | 2015.09.18 |

Source: https://lv.eosda.com

At the pre-processing stage of the dataset, a conversion of the digital number (DN) value from the multispectral band to the planet's surface reflectance value must be carried out. For Landsat-8 OLI imagery, calibration processing and conversion to planet surface reflection using the Landsat-8 OLI algorithm guide posted by USGS. There are two things that must be known when calculating the index (e.g. IEI), namely: the first, atmospheric correction must be performed, which is especially true for index between different phase images. Second, it is important that the DN value of the original image must be converted to reflectance, especially for index comparisons between various types of images. So, even though the IEI index can be easily calculated by remote sensing software, the processing procedure must be carried out according to the requirements of the remote sensing image specifications. LST were obtained from band 6 in Landsat 5 and Landsat 7 ETM + and band 10 in Landsat-8 OLI / TIRS, respectively. 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, i.e. less than 0.5 of the pixel size to avoid the uncertainty of detecting changes due to geometric correction errors on multi-temporal images. Next, the image is cropped according to the area of research, namely the city of Semarang.

2.2. Urban expansion analysis
2.2.1. Mapping of urban area. Information on urban and non-urban areas is obtained from the result of masking maps of land cover. The determination of urban and non-urban areas is only based on built-up and not built-up areas. The first step is to create a 2015 land cover map using a combination of object-based classification and visual interpretation, then the results of this map are 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. In this study, there are two methods used for mapping urban areas namely object-based classification and visual interpretation. The use of these two methods on the grounds that a large number of bare soil is classified as an urban area. This is due to the almost equal spectral value between the two objects, although it has been done by adding NDVI and NDBI information in the process of class separation. For this reason, the visual interpretation method is used to improve the quality of the results of the previous urban land cover mapping method. 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) [18] and finds an accuracy rate of 97.3% (Overall accuracy).

Mapping of 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:

\[
\text{UEII}_{i,t-t+n} = \frac{\text{UA}_{i,t+n} - \text{UA}_{i,t}}{\text{TA}_i} \times 100 
\]

Where is \(\text{UEII}_{i,t-t+n}\) is the intensity of urban expansion for units of spatial \(i\) over the time span \(t\) and \(t+n\); \(\text{UA}_{i,t+n}\) and \(\text{UA}_{i,t}\) represents the urban land area of the unit of spatial \(i\) at that time \(t+n\) and \(t\); \(\text{TA}_i\) is the total area of the unit of spatial \(i\). The unit of spatial in this study is a grid index of 0.25 km x 0.25 km, and UEII at the level of spatial units with index values between 0-1, where the value of 0 is experiencing a low rate of increase in urban areas and the value of 1 is experiencing a high rate of increase in urban areas.

2.2.2. Annual urban growth rate. To evaluate the velocity of urban expansion of Semarang in all stages, the annual urban growth rate (\(\text{AGR}_a\)) (Equation 2) and the standardized annual urban growth rate (%) (\(\text{AGR} \%)\) (Equation 3) 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:

\[
\text{AGR}_a = \frac{A_{\text{end}} - A_{\text{start}}}{d} 
\]

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

Where \(\text{AGR}_a\) (km²/year) and \(\text{AGR} \%)\) are the annual growth and is the standardized annual growth rate (%), \(A_{\text{start}}\) and \(A_{\text{end}}\) are the respective urban areas in the beginning and the last periods, and \(d\) is the study time span for a certain time.

2.3. Selection of parameters ecological and construction of Integrated Ecological Index (IEI)

2.3.1. Ecological parameters. The proposed ecological index must be able to appear in the structure of a single indicator or to synthesize information from four indicators. The indicators are strived to represent urban land that is assumed to be formed by built areas, vegetation areas, and microclimates which also influence the formation and development of urban ecosystems. In this study, NDBI (Equation 4) was chosen as the built-up aggregation degree to exploit the observed difference between the spectral response of the built-up area in the NIR and MIR sections of the electromagnetic spectrum [19]; NDSI (Equation 5) is considered as a dryness degree to show the distribution of vacant land and one of the
elements that affect the microclimate conditions of the city, NDSI consists of a combination of a vacant land index (BSI) (Equation 6) and normalized surface-resistant index of differences (NDISI). BSI (Bare Soil Index) is used in discrimination between built-up areas and vacant land. NDISI is designed to utilize high SWIR reflectance on surfaces in the form of sand and soil. Water noise is represented by MNDWI (Equation 7) and thermal is represented by thermal channels (TIR) in the form of LST values; NDMI (Equation 9) can be used to obtain information about moisture degree to reflect soil water content and vegetation canopy [20]; SAVI (Equation 7) was chosen to show the green degree because it is more dominant in describing soil vegetation systems in urban areas and this index is theoretically more reliable than NDVI [21]. Four ecological parameters, respectively, are calculated as follow:

\[ \text{NDBI} = \frac{\text{SWIR1} - \text{NIR}}{\text{SWIR1} + \text{NIR}} \]  
\[ \text{NDSI} = \frac{\text{BSI} + \text{NDISI}}{2} \]  
\[ \text{BSI} = \frac{\text{SWIR1} + \text{RED} - \text{BLUE} - \text{NIR}}{\text{SWIR1} + \text{RED} + \text{BLUE} + \text{NIR}} \]  
\[ \text{MNDWI} = \frac{\text{GREEN} - \text{SWIR1}}{\text{GREEN} + \text{SWIR1}} \]  
\[ \text{NDISI} = \frac{\text{TIR} - \left[ \frac{\text{MNDWI} + \text{NIR} + \text{SWIR1}}{3} \right]}{\text{TIR} + \left[ \frac{\text{MNDWI} + \text{NIR} + \text{SWIR1}}{3} \right]} \]  
\[ \text{NDMI} = \frac{\text{NIR} - \text{SWIR2}}{\text{NIR} + \text{SWIR2}} \]  
\[ \text{SAVI} = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED} + L} \] , where \( L = 0.5 \) (10)

2.3.2. Construction of IEI. How to represent many variables in one variable is the key to this construction of IEI. In this study, we have chosen the Principal Component Analysis (PCA) method for construction IEI. PCA not only simplifies complexion in data of high dimensions but also defending trends and patterns [22]. PCA is a multivariate statistical analysis method that can simplify complex problems by converting data matrices into a number of variables and explaining the interrelationships among several variables. It adopts the method of rotating the coordinate axis so that it will centralize multi-dimensional information into several feature components, and each feature component will represent certain feature information. By rotating the axis of the characteristic spectral space to minimize the correlation between indicators, the main information is concentrated in the first main components. Another advantage of using PCA is that the weight of each indicator is not determined manually, but automatically and objectively determined according to the percent variance contribution of the principal component that taken as the weight coefficients of each principal component. Moreover, the determination of weight can also be decided without a priori knowledge of how these variables are related to environment pressures [23]. The result of this study, PC1 has the highest percentage of eigenvalues, this indicates that this component has integrated most of the characteristics of all parameters. PC1 is then used to construct IEI in this study. The IEI values are then normalized from 0 to 1 so that between different-study periods have the same standard values to be compared temporally. The higher the IEI value indicates better urban ecological status and lower values indicating poorer ecological. The formulation of the index (IEI) is as follows:

\[ \text{IEI} = 1 - (\text{PC1})_{[\{f(\text{SAVI, NDMI, NDSI, NDBI})\}]} = 1 - \sum_{i=1}^{m} a_i(\text{PC}i) \]  
Where PC1 is the first principal component of PCA; ai is variance contribution weight of principal component; m is the number of basic ecological parameters; and PCi is the first principal component for each integrated ecological index i [17].
2.4. Statistical analysis
To measure the strength and direction of the linear relationship between the intensity of urban expansion and urban ecological status (IEI) was examined by the Pearson Correlation analysis method. Figure 2 shows scatter diagram of data samples.

![Figure 2. Scatter chart between urban expansion intensity index and integrated ecological index](image)

3. Result and Discussion
3.1. Spatiotemporal change in urban expansion
During the decade between 2005 and 2015, the Semarang region had suffered rapid urban expansion (Figure 3). In 2005, the total urban area was 169.18 km$^2$, which represented 43.65% of the study area, whereas, in 2015, the urban area had increasingly expanded to 208.16 km$^2$, which amounted to 53.70% of the study area (Figure 4). The urban areas increased by more than 10% in a decade. The growth rate increased from 2.7 km$^2$ year$^{-1}$ between 2005 and 2011 to 5.8 km$^2$ year$^{-1}$ between 2011 and 2015. The results show that the annual growth rate in the 2011-2015 period doubled from the 2005-2011 period, which was originally 1.51% to 3% (Table 2).

![Figure 3. Urban expansion in Semarang City](image)

The area of urban expansion achieved 38.97 km$^2$ in 10 years, and the urban expansion intensity index values were 0.7 and 1.5 in the periods of 2005-2011 and 2011-2015 (Table 2), respectively. The higher value of the urban expansion intensity index indicates that the city experienced a great urban expansion, this is shown in the 2011-2015 period. The distribution of urban land in Semarang began to disperse to the east and south of the city in the period 2005-2011 but in the period 2011-2015 almost all directions (i.e. south, southeast, west, and southwest) except the northern part (Figure 5).
Figure 4. Urban land growth in the city of Semarang in the period 2005-2015

Table 2. Urban expansion in Semarang city in the period 2005-2015

| Period       | Expansion area (Km²) | Annual expansion area (Km²y⁻¹) | Standardized annual growth rate (%) | Urban expansion intensity index |
|--------------|----------------------|---------------------------------|-----------------------------------|-------------------------------|
| 2005-2011    | 15.94                | 2.7                             | 1.51                              | 0.7                           |
| 2011-2015    | 23.04                | 5.8                             | 3.0                               | 1.5                           |

Source: analysis

Figure 5. Urban expansion intensity in Semarang City

3.2. Changes of urban ecological status

The results showed that the area of ecological status is extremely poor and poor is mostly distributed on urban land, while areas with good and excellent ecological status are towards the outside of urban areas to the southwest and south part of Semarang city with high vegetation coverage (Figure 6). From 2005 to 2011, the level of good ecological status had the highest proportion, but the proportion in 2015 declined. Meanwhile, from 2005, 2011 and 2015 the proportion of ecological status is poor and extremely poor is increasing (Table 3). The areas of good and excellent ecological status decreased by 61.91 km² and 27.22 km² respectively from 2005 to 2015. Conversely, areas with poor and extremely poor ecological status increased by 22.42 km² and 5 km² respectively from 2005 to 2011 to 49.43 km² and 12.29 km² in 2011 to 2015. In the 2011-2015 period, the ecological status was poor and extremely poor more than doubled. The area of poor ecological status is mainly spread to the west, south, southeast, and the east of the city of Semarang.
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Figure 6. Urban ecological status based on IEI in Semarang city

Table 3. Area of urban ecological status in Semarang city

| Year  | Extremely poor | %     | Poor | %     | Good | %     | Excellent | %     |
|-------|----------------|-------|------|-------|------|-------|-----------|-------|
| 2005  | 3.13           | 0.83% | 79.12| 21.07%| 196.16| 52.24%| 97.08     | 25.85%|
| 2011  | 8.13           | 2.17% | 101.53| 27.04%| 178.82| 47.62%| 87.02     | 23.17%|
| 2015  | 20.42          | 5.44% | 150.96| 40.20%| 134.25| 35.75%| 69.86     | 18.61%|

Source: analysis

3.3. Discussion

As the center of the Semarang metropolitan area (SMR) and one of the major cities on the island of Java, Semarang has been developing rapidly. The analysis shows that there has been an increase in built-up area during the decade between 2005 and 2015. Rapid increase occurred between 2011 and 2015 (Figure 3), in this period the annual expansion urban area has doubled, this should be a concern for land use planning policymakers, because of this increase can introduce various environmental and ecological urban problems, including change the urban microclimate and increase the risk of surface runoff [9].

Semarang has been experiencing an increase in population and city development occurs both inside and outside the city limits, it is realized in the construction of roads and housing, expansion of industrial and commercial areas. In 1990, the center of Semarang became a center of community activity, over time, the center of the city became more crowded the building, this led to the emergence of new growth centers that spread across the east and south of the city [14]. This new growth center encourages intensive urban land expansion to the periphery because outside of urban area Semarang there is a wider development area that can accommodate development, for example for industrial zones and universities. In the city of Semarang, this occurred in the Mijen sub-district with an industrial zone and a satellite city as well as a Tembalang sub-district with the existence of the integrated campus of Diponegoro University. In addition, the intensive development towards the south and east because the Semarang government has facilitated large developers to develop new settlements [24]. This is in accordance with Li et al (2011) [25] which stated that urban spatial expansion can be considered a continuous process that occupies spatial resources suitable for urban development, to comply with the demands of socio-economic development.

Figure 6 shows the spatial distribution of IEI as an urban ecological status classified into four categories using equal intervals, namely excellent, good, poor and extremely poor. IEI is an integrated ecological index that is able to assess the urban ecological status [17] formed by using PC1. There are four indicators that represent pressure on the urban environment, each of which is caused by human activities (i.e. built-up aggregation degree) represented by the NDBI, changes in environmental conditions (i.e. green degree) represented by SAVI and climate change responses (i.e. dryness degree
and moisture degree) represented by NDSI and NDMI. IEI can be used for spatiotemporal observations by normalizing the index value of the results of PC1 so that it has the same scale of values, but this will greatly depend on the quality of the RS image. The RS image used must be a cloud-free image because it will affect the variability of the surface spectral reflectance [26].

In this research, there was a decrease in the urban ecological status during the period 2005 to 2015. In general, the urban ecological status in the north and towards the city center are categorized as poor, which poorer compared to the southern part centrifuged towards the periphery of Semarang. The prominent characteristics of the IEI distribution show that from 2005 to 2015 there was an expansion of the poor urban ecological class, especially towards the west, east, southeast, and parts of the south. The extent and direction of deteriorating urban ecological status are in line with urban expansion that occurred in the same time period (Figure 5).

Previous studies showed that there were significant changes in land cover from 2005 to 2017, which resulted in the urban spread that led to the suburbs of Semarang [27]. Urban sprawl and city expansion that leads to an increase in the percentage of impervious surfaces are usually associated with areas covered by high surface temperatures that will affect the ecological environment [28]. The northern and central areas of Semarang were identified as areas with poor and extremely poor ecological status. In this region, the most critical environmental conditions are based on LST and the availability of vegetation cover [17]. Because the city centre is filled with concrete buildings, asphalt roads, factories and harbours that cause low albedo, which is identified as the main source of high LST accompanied by the distribution of small vegetation, this worsens the urban ecological status (Figure 6). The IEI, which is used to assess urban ecological status, has a significant effect on LST both in terms of spatial correlation characteristics and quantitative relationships [17]. Therefore, local government policies related to spatial planning for the green city can effectively minimize the high-temperature environment. From the description above, there is a relationship between the intensity of urban expansion and urban ecological status. Meanwhile, the Pearson correlation calculation results show that the expansion of the city has a negative impact on the integrated ecological index both in 2005-2011 and 2011-2015 with correlations of -0.816 and -0.671 (significant < 0.01), respectively. The results of the study indicate that the deteriorating ecological status can be caused by the expansion of urbanization. Therefore, to reduce this impact the city development plan and rational city management steps must be implemented.

4. Conclusions
This study shows that the urban areas of Semarang has grown at a rapid rate, especially in the period 2011-2015. So the latest information about ecological status is needed to monitor and manage the quality of the urban environment. This study shows that for a decade urban expansion and decline in urban ecological status mainly led to the west, south, southeast and east of the city. The ecological status is of good and excellent values in the southwest part must be maintained and must be a concern for the government of Semarang. The urban expansion intensity and the urban ecological status (IEI) have opposite relationships which infers that an increase in the intensity of urban expansion follows the decline in urban ecological status. The established IEI ecological index is based entirely on remote sensing technology, with natural factors as the main indicators and simple calculations. There are no artificial weighting and threshold settings. This index can be used for monitoring and evaluation of urban ecological status.

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