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Cover Page Footnote

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URBAN FLOOD AND ITS CORRELATION WITH BUILT-UP AREA IN SEMARANG, INDONESIA

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ABSTRACT

The expansion of urban areas is closely related to environmental problems such as changes in land use, flooding, and land subsidence. Semarang is a city with reasonably rapid development and a high land change experiencing floods and land subsidence. This paper will discuss land transformation caused by urban growth and its implications. It uses a combination of geospatial techniques and cloud computing Google Earth Engine (GEE) to carry out mapping over a large area without being constrained by computer capabilities. This study found that the built-up area in 2010 occupied 36.27% of the city, and it went up to 59.79% in 2021, in eastern, south-eastern, and northern parts of Semarang City in the last six years. Most of the built-up areas, especially those located in coastal areas, are located in areas with a high rate of land subsidence and urban flooding. The built-up area also significantly increases residential areas compared to other land cover types such as vegetation, open land, and water bodies. Built-up area growth also contributes to the rate of land conversion in Semarang City, especially in Mijen Regency; the vegetation cover was transformed into industrial areas and housing, which heavily stressed the land and environment. This leads to the increasing subsidence on the land of that area, which resulted in increasing urban flooding.

Keywords*: Built-up area; land cover; land subsidence; flood; urban growth*

INTRODUCTION

The growth of Semarang City has resulted in an increase in the amount of built-up land in the city center area. The growth of Semarang's city center region, on the other hand, is reducing the amount of green open space (Pigawati *et al.*, 2019). Population growth and per capita land consumption are the two most essential elements in urban development (Nicolau *et al.*, 2019). Cities have significant populations growing at a rapid rate (Jat *et al.*, 2017). Urban flooding is the most common type of disaster in the urban environment that affects people the most. This regularly happens in rainy seasons, especially in Indonesia's big cities, such as Semarang, the capital city of Central Java Provinces.

Unplanned urbanization processes increase the recurrence of these hazards due to the lack of green space and seepage for run-off water due to impermeable soil in urban areas. Thus, land-use and land-cover detection changes are essential factors for investigating urban flooding (Dalanhol, 2020). This urbanization which happened rapidly is a common phenomenon found in many urban areas in different countries (Handayani & Rudiarto, 2014), and Indonesia is no exception in the list.

Climate change is also a key factor since it influences rainfall patterns and accounts for the intensity of flooding events. The lack of green space due to massive infrastructure development and rainfall intensity creates more flooding in urban areas. Semarang is also affected by this predominantly since the area consists of highland and lowland adjacent to the sea, making Semarang City much more prone to flood (Hermini et al. 2018). As a downstream area, Semarang City becomes an abundance of water that overflows from the rivers, resulting in floods in the rainy season. The tidal wave could become the cause of coastal flooding, especially in the northern area of Semarang.

Flood management infrastructure used to control water flow through Semarang city for many years, such as East Flood Canal and West Flood Canal, can no longer reduce flood risk (Batubara et al., 2021). For example, the flood on 5 February 2021 has severely disrupted the city transportation systems, with Tawang and Poncol stations and airports could not operated. Many people had to evacuate their homes, especially in their northern neighborhoods.

The project *"GroundUp: A practice-based analysis of groundwater governance for integrated urban water resource*," which was supported by Ristek DIKTI (Indonesia) and by the Dutch Research Council (NWO), suggested three solutions to overcome the damage from urban flooding in Semarang City. First, to reduce the groundwater use in Semarang, second to limit the extensive infrastructure, and third to shape the urban resident's behavior. That research showed the significance of people's decisions and actions shaping the distribution of surface and groundwater throughout the city, leading to the assumption that the urban population affects the flood management practice in Semarang City.

Floods in Semarang City are closely related to land subsidence (Suhelmi *et al.*, 2014; Pujiastuti *et al.*, 2016). Most of the flooding occurred in the northern part of Semarang, where the area has a reasonably high PMT rate (Andreas *et al.*, 2018). Sarah et al. (2014) explained that Semarang City had experienced intensive land subsidence since the 1980s. Land Subsidence is caused by three leading causes: natural consolidation of unconsolidated clay deposits, excessive use of groundwater, and loading (buildings or embankments). It is triggered by development in Semarang City due to population growth and economic and industrial activities to accelerate land subsidence (Murdohardono, et al., 2002; Abidin et al., 2010; Ramadhan et al., 2014).

Moreover, the research from Handayani, W and Rudiarto I (2014) also showed that Semarang Metropolitan Area has rapid urban growth followed by a high rate of land transformation and resulting in a typical pattern with Asian Cities such as Jakarta, Bangkok, and Metro Manila. The result is observed from two leading indicators: the change of built-up area as land transformation and population density.

Thus, this study is conducted to understand better urban flooding in Semarang with the urban growth that happened due to environmental hazards represented by land subsidence and urbanization, which currently leads to land transformation to accommodate people's needs. The outcome of this study can become a consideration for Semarang City's government to create a better policy and decision-making in city's future planning to prevent further damage that could probably happen due to urban flooding.

Urban Growth and Rapid Urbanization in the City

A city consists of numerous interactive sub-systems that create a complex system. It is affected by several factors such as government policies, land use transformation, population growth, transportation infrastructure, and market behavior (Rui, 2013). Over time, a city becomes much more complex, and consequently, the social, economic, and cultural development conditions between the city population and environment will change (Novin & Khosravi, 2016).

Urban growth is an inevitable phenomenon that depends on several internal and external factors (Adeel, 2010). The world also has encountered quick and uncommon urban development due to the industrial revolution and worldwide economy (Tajbakhsh et al., 2016). According to the 2018 Revision of World Urbanization Prospects (United Nations, 2019), more people live in urban areas, around 55 percent of the world's population in 2018, and are projected into two-thirds of the global population in 2050.

As one of the developing countries, Indonesia is expected to experience rapid urbanization in the coming decades, from 41 percent in 2018 to 59 percent in 2050 for the proportion of the urban population (United Nations, 2019). Therefore, the study of urban growth is becoming a trend since understanding how urban areas are changing inside the landscape becomes increasingly important (Hadi et al., 2016). Urban areas are often the most vital indicators of human interaction with the environment, and the detected information from remote sensing and GIS approach is taken into account for policymaking (Mosammam et al., 2017). Urban growth analysis can also help understand the potential impacts on a region's water resources, economy, and people's behavior (Novin & Khosravi, 2016).

Rapid urbanization and urban growth also lead to higher flood risk. Flood is more frequent in the urban areas, most of which are near the coastal line, such as Semarang City (Yuwono, et al., 2021). Handayani et al. (2018) found that urban flooding is caused by water overflowing from the river and land-use change combined with improper drainage systems. It is believed that densification plays a significant influence in the increasing occurrence of flooding in urban areas.

Szwagrzyk et al. (2018) model projected land-use change in the Polish Carpathians area for flood risk. The three model LUCC scenario for the year 2060 leads to a different outcome; however, there is a substantial increase in flood-prone areas related to the prediction degree of urbanization. Another research from Dammalage and Jayasinghe (2019) also leads to finding that the change of land-use in the area of Kelani River watershed, Colombo district which changed into urban area having a significant impact on flood inundation.

Employing Geographic Information System and Remote Sensing technique, the relationship between urban growth, land transformation, and urban flooding could be assessed and investigated for further analysis, such as creating decision-making or policy regulation in flood management practices and planning.

STUDY AREA

Semarang is the capital of Central Java province, located on the northern coast of Java Island, Indonesia. It is located at the -6o58' (latitude) and +110o25' (longitude) and covers an area of about 373.7 km2. The topography of Semarang City consists of hills, lowlands, and coastal regions (Hermini et al., 2018). As it is located downstream, Semarang City is more prone to flooding from overflowing water from the river and tidal waves (coastal flood).

Semarang city is the eighth populated city in Indonesia, with almost 2.000.000 people in this city now. The number of people in Semarang has doubled in 20 years (Wilonoyudho, 2010). The size of the population in Semarang Metropolitan Area is being projected to 2,100,000 inhabitants in 2030 (CBS, 2010 in Handayani & Rudiarto, 2014). The rapid expansion of the urban population leads to a need to accommodate the required land demand for such urban activities. This resulted in numerous infrastructure developments and land use transformation critical for the urban environment. Therefore, the city was selected to be study case for this study as depicted in Figure 1.

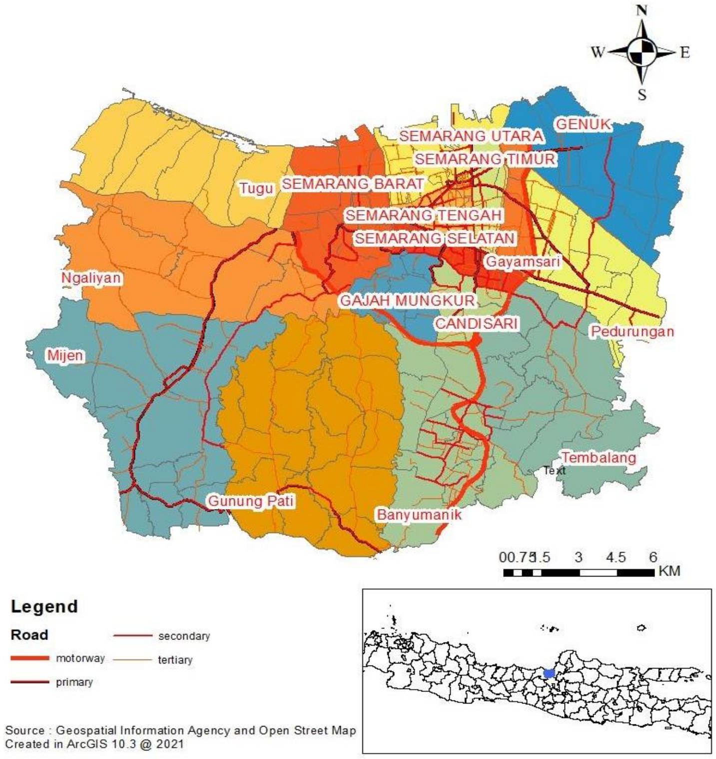

Figure 1. Semarang city was chosen as a study area

The massive development of infrastructure and settlement is becoming a concern since urban green space is being transformed into a settlement area. Less green spaces contribute to the increase of surface temperature in urban land and run-off water sewage. This could create more disasters such as urban flooding. These are all the reasons why Semarang is chosen as the study area.

In this research, we also employed a segmentation process on night time dataset using VIIRS and NOAA dataset in 2021 to perceive the urban area in Java Island (Figure 2). The red area in figure 2 indicated urban area by night time satellite imageries dataset, namely Jabodetabek area, Bandung, Tegal, Pekalongan, Purwokerto, Solo, Jogja, Semarang and Surabaya. This is also proven data for limiting the urban area in Central Java, and one of them is Semarang City.

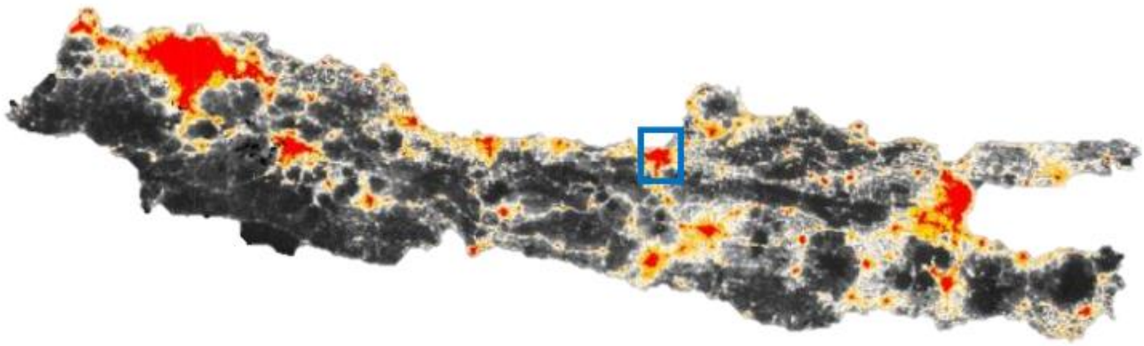

Figure 2. Urban area in Java Island from segmentation of night time dataset in 2021

METHODS

Data are obtained from several sources:

1. Flood inundation data series derived from satellite imageries. The year was chosen by several flooding events and precipitation data from Meteorological, Climatological, and Geophysical Agency (MCGA) and Central Bureau of Statistics (CBS).
2. Land use/land cover derived from Landsat from 2010 to 2021 to observe the transformation of the land that might be contributed to the rate of flooding.
3. Extraction of built-up area employed by using spectral indices from satellite imageries.
4. Reference data or ground-truth data for validation from a government institution.

The research methodology depicted in figure 3. The software used is Google Earth Engine and ArcGIS and some statistical software such as Excel or SPSS.

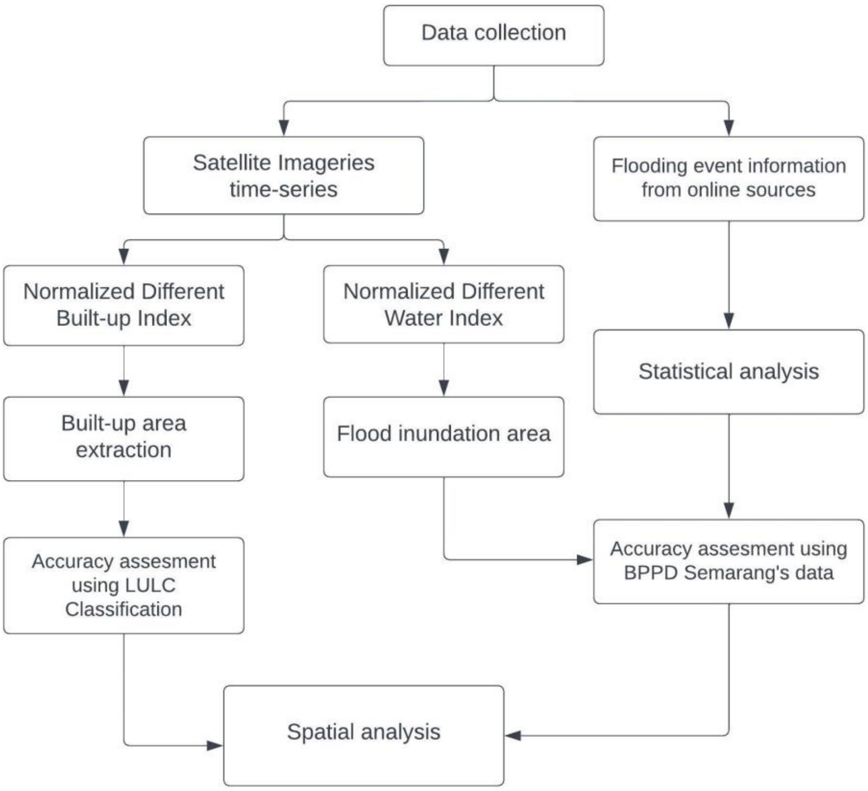

Figure 3. Research Design

Data processing includes pre-processing satellite imageries such as geometric correction, radiometric correction, and atmospheric correction. Masking and mosaicking were also needed to cover the cloud area with clearer images. Then, a built-up area analysis is required to be done in time series. The analysis will be employed by using Normalized Difference Built-up Index (NDBI) in Landsat (Hadi et al. 2016; Handayani & Rudiarto, 2014) to obtain the information about the built-up expansion from time to time. The formulation of NDBI was calculated using Shortwave Infrared and Near-Infrared of satellite imageries spectral value as written in the equation below.

$$NDBI = (SWIR - NIR) / (SWIR + NIR)$$

Time series data of satellite imageries to detect the change of land use/land cover must be classified. For this research, we employed CART (Classification and Regression Tree) as the method for land use classification. CART is an essential machine learning algorithm under supervised learning and can be used for a wide variety of research, not limited to land cover or land-use change only.

CART refers to the two types of decision trees. The first one is classification trees; when the target variable is categorical, the tree is used to find the class under which the target variable is most likely to be located. The second one is regression trees used to model or forecast what is likely to happen in the future by using the continuous variable value.

Meanwhile, the flood is delineated using Sentinel 2-MSI and Landsat by subtracting NDWI (Normalized Difference Water Index) in the dry and wet seasons (Mehmood et al., 2021). Normalize Difference Water Index (NDWI) is utilized for surface water analysis. It can enhance water information efficiently in drought monitoring or flood analysis. NDWI was developed to identify water-related features in the surface (Mehmood et al., 2021). This index uses the near-infrared (NIR) and the Short-Wave Infrared (SWIR) bands. NDWI can be calculated by the following formula:

NDWI = (NIR – SWIR) / (NIR + SWIR)

The data that is observed was from 2010 to 2021 of a flooding event. We selected 2010, 2014, 2016, and 2021 years of flooding events as indicated in Handayani et al. (2020), which assessed the flooding event in Central Java from 2009 to 2018. That research found that river crossing Semarang City had higher rainfall intensity in the following years.

RESULTS AND DISCUSSION

Urban Growth from 2010 to 2021

The urban expansion was calculated by employing an index called NDBI by calculating values from Shortwave Infrared and Near-Infrared wavelength of Landsat satellite imageries. The delineation was based on the mean and standard deviation threshold calculated from each image index. The output images are depicted in figure 4.

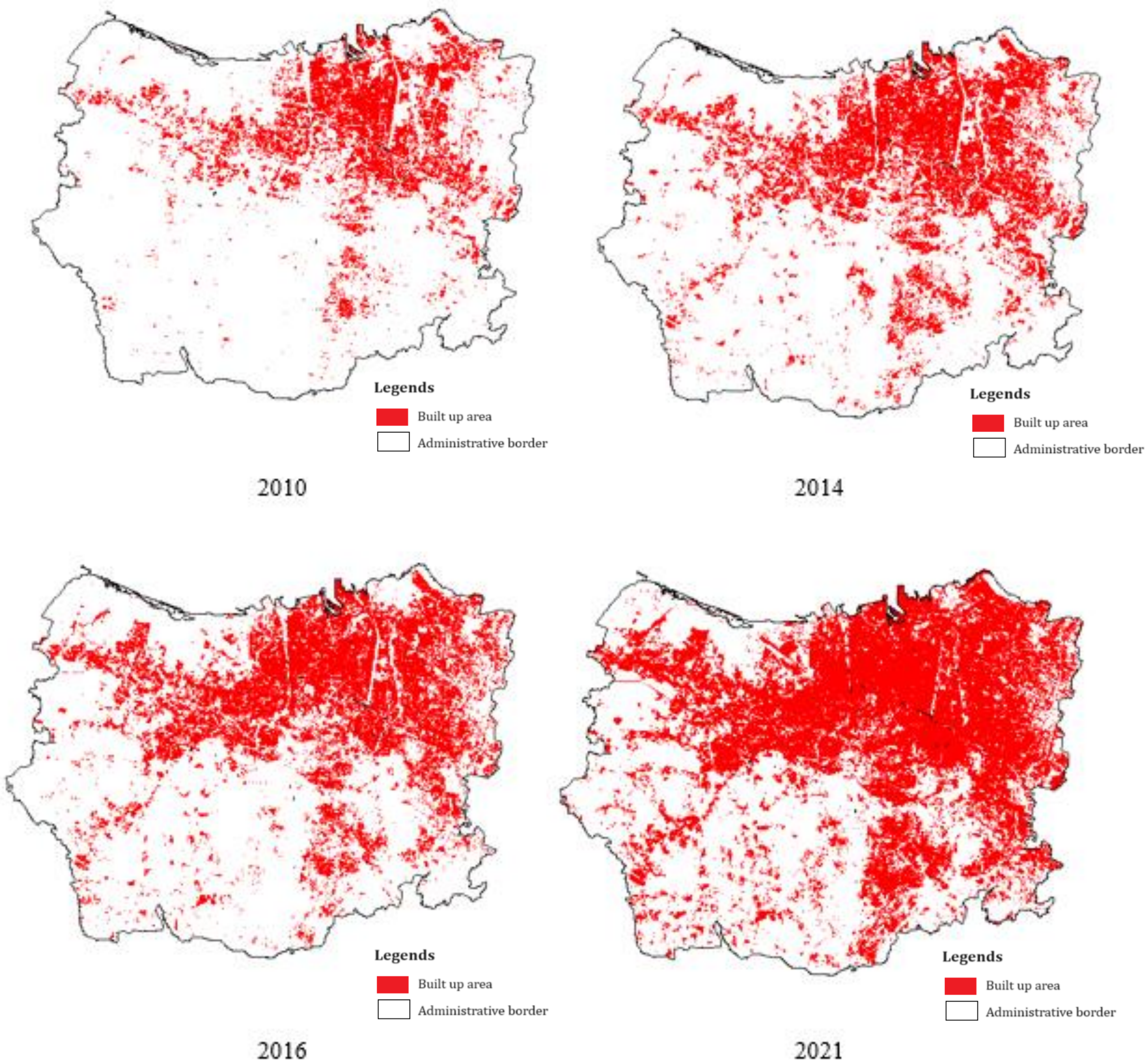

Figure 4. Urban growth from 2010 to 2020 indicated by red color

To obtain the information of the rate change of built-up area, NDBI statistic data is calculated by pixel in ENVI. The built-up area in 2010 occupied 36.27 % of the city, and it went up to 59.79 % in 2021. Overall, it showed a significant increase, especially in the eastern, south-eastern, and south-western of Semarang City. The city's growth from 2010 to 2014 was also noticeable for more than 7 % of city expansion. The most likely cause is the rapid development of housing estates and education institutions (Hadi et al., 2016).

Meanwhile, in 2014 the portion of built-up was around 43.47 % of the city and then expanded to 45.22 % in 2016. The growth in the span year of 2016 to 2021 was calculated as 14,6 %, while from 2010 to 2016 contributed 9 %. It means the city's growth has increased by 1.5 times in six years. While in the span year of 2014-2016, the change is only about 1.8 %. In the last six years, the expanded urban area was heavily focused on the eastern, south-eastern, and northern parts of Semarang City.

The extracted urban area from the calculation of spectral indices was cross-checked from another satellite imageries that was higher in resolution by observing the urban and non-urban area and employed them in the confusion matrix. Overall accuracy was calculated to perceive how similar the output or produce an image with the reference image in the urban area. All output images produce around 81 to 87 percent of overall accuracy with different sampling points used in each image.

The land transformation from 2010, 2014, 2016 to 2021

The land transformation is observed by calculating the land cover area in Landsat Satellite Imageries in observed years, ranging from 2010 to 2021. The land cover is classified using the CART method. CART or Classification and Regression Technique is a nonparametric technique that could explain categorical or continuous dependent variables in terms of independent variables. The CART algorithm is a kind of classification algorithm that is needed to build a decision tree. It is a basic machine learning algorithm that could solve various problems.

All of the process was employed in Google Earth Engine. The classified was divided by 4 main classes which are barren, water, vegetation and urban area. The increase of urban area is all happening in each observed year and predicted to increase in the future as well. The classification of land use is depicted in figure 5 and calculation of those area could be seen in table 1. The vegetation areas were decrease by 14 % from 2010 to 2021. Overall urban area had been increasing and vegetation area were decreasing.

Table 1. Area, each land class, calculated in square kilometres

Land Class	Area (km^2)			
	2010	2014	2016	2021
Vegetation	199.55	188.04	169.04	142.87
Urban	134.27	144.27	156.08	183.90
Water	30.92	33.29	37.21	36.81
Barren	19.67	19.22	22.50	21.24

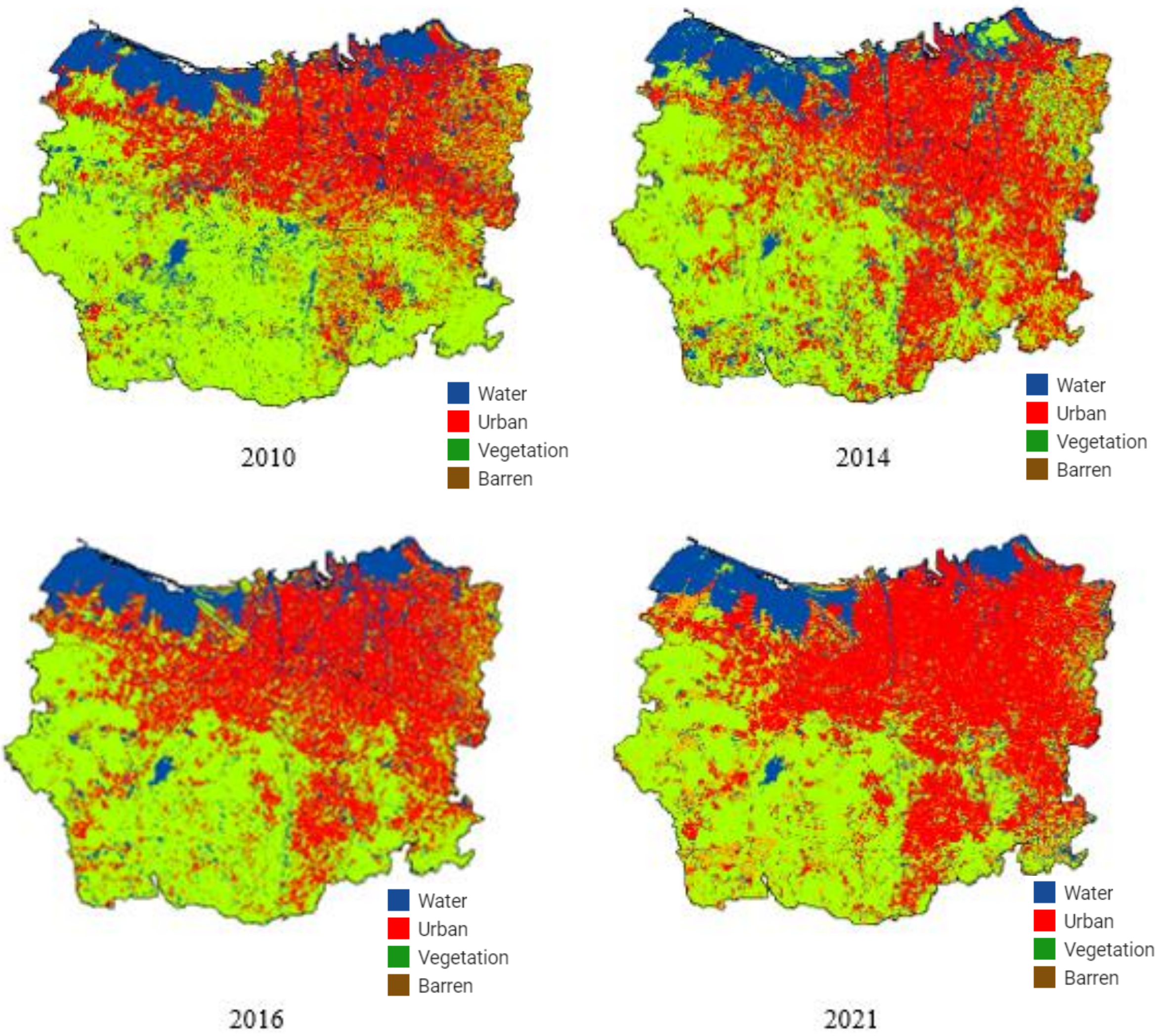

Figure 5. Land Use Transformation from 2010 to 2021. The green color indicates vegetation, red color for the urban area, blue color for water, and brown color for barren or open area land.

The water change might be likely because of the difference in water discharge. The increase of water area in 2016 could be because of the construction of new dams and reservoirs for urban flooding prevention and mitigation, such as reservoirs in the area of Diponegoro University and Jatibarang, which were finished in 2015-2016. The data and figure are depicted in Table 1 and Figure 6.

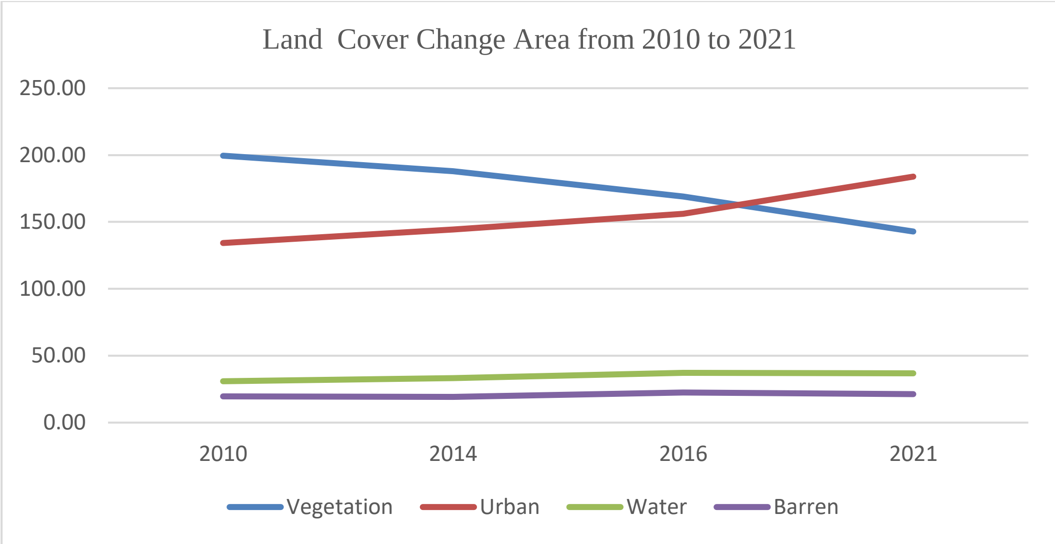

Figure 6. Land use transformation by area calculation from 2010 to 2021(km^2)

The visualization data of area calculation from land cover are shown in figure 6. Note that the road area was not calculated at all in all observed years since the image resolution is not adequate to identify the road as Landsat spatial resolution is around 30 meters only. Therefore, the area calculation might not be that accurate. The overall accuracy calculated in Google Earth Engine for LUCC in 2010, 2014, 2016, and 2021 in sequence order is 78%, 81%, 77% and, 78%. The accuracy might be increased by the utilization of higher spatial resolution of satellite imageries or aerial photos. The purpose of LULC classification is to assess the accuracy of NDBI result in the previous sections.

The flooded area from 2010 to 2021, calculated using NDWI in the wet and dry season

The flooded area was delineated using the Normalized Difference Water Index (NDWI) calculated in the wet and dry season, then subtracting them to find the inundation area (Mehmood et al., 2021). The wet season imageries were employed from late December to late March, while the dry season imageries were selected from late June to late September.

The threshold selected was from a value of 0.2; this value was selected through trial and error. The data statistic is calculated in ENVI by pixel count. For the dry season, the water accumulation is counted around 9-10 percent of the area in all observed years. For the wet season, the highest accumulation of surface water was in 2010, with around 39% of the area.

The flooded area was also highest in 2010, with 29.8 % of the area. This might occur likely due to the heavy precipitation at that time. All of the observed areas were reportedly found that inundated area was around 20 to 30 % in 2010 to 2021, which was heavily concentrated in urban areas and the northern part predominantly northeastern part of Semarang.

Validation was conducted in 2021 flooded area by utilization of Field inundation data in 2021 that was collected by the Regional Department of Disaster Management Agency (BPBD) Semarang. There are 27 points of inundation that are depicted in the appendices.

All points overlapped with the flooded area in 2021 and were placed within the flooded area, as shown in figure 7. When we tried to employ all flood data regarding tidal (rob) or local flood and process accuracy assessment using confusion matrix, we obtained only 78.15 % overall accuracy. This overall accuracy value might be due to the south of Semarang City or downtown area, which did not have any field data for the flood. There could have another experiment to find the correct adjustment of the threshold to perceive the accuracy of the output model.

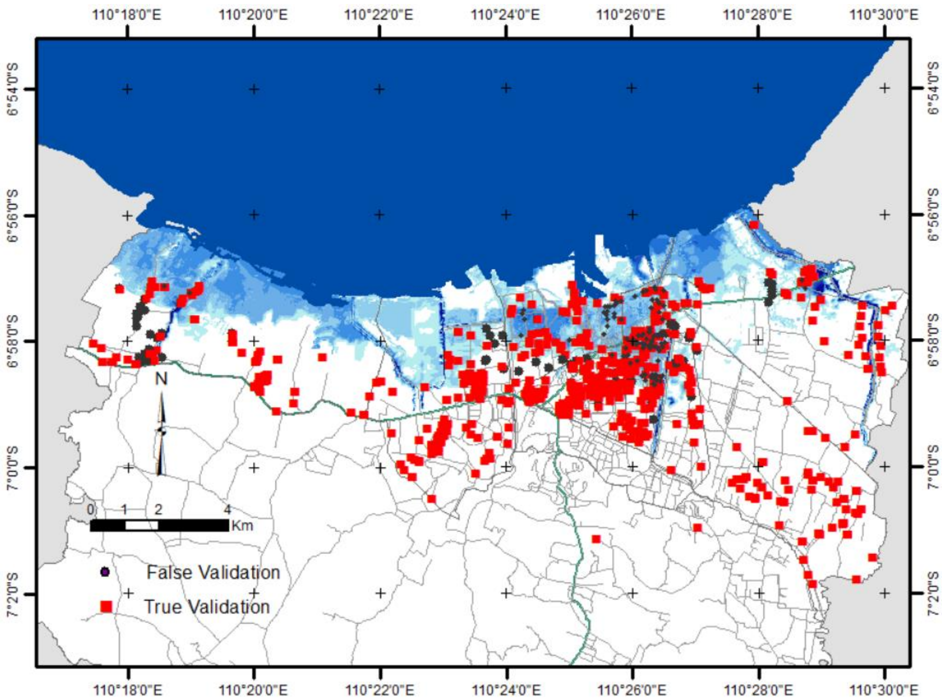

Figure 7. Validation data from field survey and Regional Disaster Management Agency/Badan Penanggulangan Bencana Daerah Semarang (BPBD Semarang)

DISCUSSION

The built-up area has developed significantly to the southwest and southeast of Semarang, where the area is heavily concentrated with industrial growth and residential area. Moreover, Hadi et al. (2016) have found that the expansion of built-up correlates with education institution establishment besides the housing development, especially in the downtown. Meanwhile, Wilonoyudho, S. (2010) researched the urbanization in Semarang before the year 2010 was happening because of inward migration to the city.

Built-up area growth also contributes to the rate of land conversion in Semarang City, especially in Mijen Regency; the vegetation cover was transformed into industrial areas and housing, which heavily stressed the land and environment. This leads to the increasing subsidence on the land of that area, which resulted in increasing tidal floods or rob. Although there is a significant development of the built-up area, the vegetation was still maintained. There were some changes in terms of the area of vegetation; however, the conversion is not significant.

When analyzing the built-up with the rate of subsidence, the researchers obtained the information that expansion of built-up area has occurred in the area with a higher rate of land subsidence. It could be perceived from the northern part of Semarang City, where the rate of subsidence is high; nevertheless, the growth of built-up was continued to happen. Therefore, the rate of subsidence in this area becomes higher because of the stress from building construction that happens continuously.

Fluctuation of the flooded area from 2010 to 2021 contributed from many aspects, namely, meteorological factor, tidal wave, adaptation, and mitigation process. Fluctuation and mismatch between flooding and validation data are because of adaptation and image acquisitions. The algorithm for identifying flooding can be modified or combined with the other parameters to produce a more accurate model output of the flooded area. The downtown area identified as a flood might be a mistake from index calculation. Further research could carry out the implementation of a modified index to map the flood and observe the difference.

The land cover change in the area affected by the flood happened in the Northern part of Semarang, for example, Genuk and Tugu Regency. The conversion of the land cover mainly became a built-up area. The flooding did not affect the expansion of the built-up area since the expansion was still happening even though those areas were affected by the flood. The flood can be happened not only by tidal waves, but also caused by river flooding that has a repeat period of 50-year or 100-year return period. The use of a combination of satellite imageries, levelling data, and hydrological data for flooding needs to be supported with other parameters such as river geometry, water discharge, tidal wave data, and data elevation model to enhance the result.

CONCLUSION

During a period of 10 years the trend of urban built-up increased to the West, East and North of Semarang City, because it has a relatively flat geographical condition and a fairly good level of accessibility that connects two regencies, namely Kendal Regency and Demak Regency. Urban Built-up occurred quite significantly in the Semarang Utara, Semarang Tengah, and Semarang Timur district which reached almost 100 % of the total area.

The city of Semarang has changed from non-built land to built-up land, especially in suburban areas including Tembalang District, Ngaliyan District, Genuk District, Banyumanik District and Mijen District. Monument. Changes in built-up land in the Semarang City area are related to the built-up area phenomenon which is indicated by land transformation from open land cover types to settlements with changes reaching 59.79% and it contributes to land subsidence and urban flood that frequently happened in the city.

The utilization of satellite imageries and cloud computing process software such as Google Earth Egine for disaster management should be supported with other parameters to enhance the accuracy of the model result. if it is needed, fieldwork should be carried out to validate the model.

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APPENDIX

Table A.1 Inundation data point by BPBD Semarang

Name	BPBD		Model
	h min (cm)	h max (cm)	Flood
Kaligawe Street	30	70	Yes
Imam Bonjol Street	25	50	Yes
Bundaran Bubakan Street	25	50	Yes
Junction Arteri SOETA Street Gajah Raya	20	50	Yes
Genuk Arah Semarang Highway	30	50	Yes
Jalan Dongbiru Genuk	25	50	Yes
Citarum Taman Progo Street	10	30	Yes
Pattimura Street	10	40	Yes
Gebanganom Genuk Street	30	70	Yes
Sido Asih Street	25	50	Yes
Tlogosari Street	25	50	Yes
Ronggowasito Street	25	50	Yes
Raden Patah Street	40	60	Yes
Tambak Dalam Street	30	50	Yes
Tawangsari Kel. Tanjungmas	30	50	Yes
RW 4 Kelurahan Siwalan	20	35	Yes
Kp Batik Kel. Rejomulyo	20	40	Yes
Empu Tantular Street	10	40	Yes
MT Haryono Street	50	60	Yes
Sub District Kemijen	30	50	Yes
Kuningan	25	50	Yes
Panggung Lor	25	50	Yes
Muktiharjo Kidul	30	50	Yes
Panggung Kidul	10	50	Yes
Muktiharjo Lor	20	50	Yes
Tanjung Mas	20	60	Yes
Purwosari	15	45	Yes
Bandarharjo	20	100	Yes