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Sustainable urban planning: change detection of Land Use and Land Cover in Semarang, Indonesia

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SUSTAINABLE URBAN PLANNING: CHANGE DETECTION OF LAND USE AND LAND COVER IN SEMARANG, INDONESIA

by

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SUSTAINABLE URBAN PLANNING: CHANGE DETECTION OF LAND USE AND LAND COVER IN SEMARANG, INDONESIA

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ABSTRACT

Land Use and Land Cover Changes (LULCC) are occurring rapidly around the globe, particularly in developing island nations, such as Indonesia. Increasing population, the spread of suburbia, and the transition to rubber plantations have resulted in LULCC in Semarang City, Indonesia. We use the lens of the United Nations' Sustainable Development Goals (SDG) to determine potential policies to address these LULCC; however, these goals can be conflicting in regard to preserving natural landscapes and bettering the lives of the poor. We documented the LULCC in Semarang City using remote sensing, overlay analysis, optimized hot spot analysis, expert validation, and Continuous Change Detection and Classification. We focused on the period between 2006 and 2015. The implications of this study show that these geospatial analyses and big data can be used to characterize the SDGs and the complex interplay of these goals. The results from the analysis are useful in implementing policies and assisting in decision making at multiple spatial scales.

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LIST OF ABBREVIATIONS

CCDC	Continuous Change and Detection Classification
eo4sd	Earth Observation for Sustainable Development
ESA	European Space Agency
GEE	Google Earth Engine
GNI	Gross National Income
LULCC	Land Use and Land Cover Change
NIR	Near Infrared
RAF	Rubber Agroforestry
SDG	Sustainable Development Goals
UN	United Nations

INTRODUCTION

Land Use and Land Cover Changes (LULCC) are occurring around the world, particularly in areas of rapid population growth, urbanization, and areas most susceptible to climate change. The drivers of LULCC in Indonesia with its unique geographic landscape and rich ecological biodiversity require further analysis. LULCC demonstrate shifts in urbanization, human migration, and changes in economic structures. The Indonesian archipelago, with limited land area, is experiencing LULCC, driven by high population density and growth, social and economic development, and climate change and sea level rise. Indonesia's urban population has steadily increased from 50% in 2010 to 57% in 2020 (Statista, 2021). The urban population is expected to grow to 67% by 2050 (Indonesia Investments, 2017). This rapidly growing urban population must balance the need for housing and infrastructure with land for agriculture and food. Another trend in Indonesia is an increase in commercial agriculture, focusing on cash crops such as rubber. This transition is indicative of a loss of biodiversity from traditional forests but also means the presence of carbon sinking trees and an increase in economic opportunities for local farmers (Penot, 2004). Thus there is a mismatch in Indonesia's path to sustainable growth and better lives for all its people, which comes with a substantial loss of its terrestrial ecosystems and biodiversity and an increase in land degradation. This mismatch or conflict suggests that we need to focus on policies and actions to address the imbalances in LULCC.

The United Nations established Sustainable Development Goals (SDG**)** in September 2015 as a response to increasing population and consumption focusing on different aspects of sustainability prevalent in developing communities around the globe

(UN, 2015). However, the SDGs are rife with conflicts of interest. In an area like Indonesia with limited land mass and a burgeoning population, the SDG's call to simultaneously "take urgent and significant action to reduce degradation of natural habitats, halt the loss of biodiversity" (15.5) and "sustain per capita economic growth...at least 7 per cent gross domestic product growth" (8.1) and "develop...infrastructure to support economic development and human well-being" (9.1; UN, 2015). Although the goals of economic growth and infrastructure may align, they are at odds with the goal of reducing degradation and deforestation. How can any of these goals be met without actively hindering other SDGs?

Indonesia is the confluence of this conundrum of the UN SDGs. The archipelago's increasing land area limitations are marked by a loss of land to subsidence and sea-level rise, further exacerbating the rapid LULCC. Nowhere is this more dominant than in Semarang City, the seventh-largest city in Indonesia (UN, 2019). In 2006, Semarang had a population of 1.5 million, which increased to approximately 1.7 million by 2015, a growth rate of almost 22 thousand people per year (UN, 2019). In addition to population growth, the Indonesian Gross National Income (GNI) per capita nearly doubled during that same period (World Bank, 2020). Aside from its residents, Semarang is also a tropical, coastal city prone to rising sea levels and land subsidence. As such, it makes an excellent case study for LULCC in regards to the UN SDGs. Understanding why Semarang City is experiencing LULCC is essential to understanding the risks this city may face in the future and determining if these changes meet the UN SDGs. Not only are there more people in Semarang, but they are also more affluent than ever before. This new wealth and greater population can lead to an increase in infrastructure as well as increased demands for food and economic opportunity. It is critical to understand where and why changes are happening throughout the city, not only in terms of demographics but also as climate change and geology result in increasing sea levels and land subsidence. This study aims to ensure that Semarang City continues to develop and urbanize using a sustainable urban planning framework. This framework can inform policy decisions to guarantee the safety of its people and prevent loss of capital from climate change and other natural disasters. By looking at these factors, we hope to determine if Semarang City was developing sustainably before implementing the UN SDGs in 2015.

METHODS

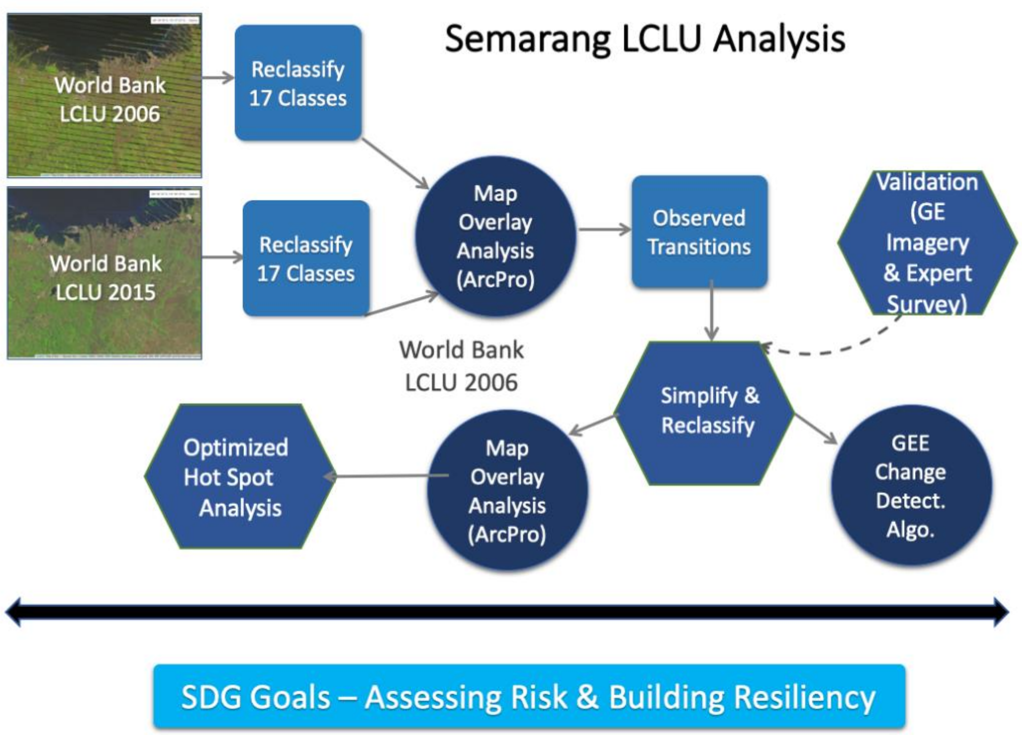

Figure 1. Workflow for Study

Figure 1 outlines the way we chose to tackle the challenging issues and complete the in-depth analysis for this study. Overlay Analysis, Reclassification, and Optimized Hot Spot Analysis were all processed using ArcGIS Pro. We completed the Continuous Change Detection and Classification (CCDC) using Google Earth Engine (GEE) with code modified from others' research (Zhu and Woodcock, 2014; Arevalo et al., 2020; Appendix A). Overlay analyses are used to determine the intersection of areas with desired features. For this analysis, we created an overlay of all LULC in 2006 and 2015 and then removed all parcels where the LULC did not change between those periods. The optimized hot spot analysis uses Getis-Ord Gi* to determine parcels that are significantly clustered near other parcels with a similar attribute, in this case the change in LULC.

Finally, the CCDC is an algorithm that detects changes in patterns of Near Infrared (NIR) in study areas. In addition to detecting the changes, it also approximates the year these changes occurred and how many changes in pattern occurred over the designated time period. NIR is an ideal band to use for CCDC because it is a key indicator for loss of biomass and agriculture. Thus, it is good for examining urbanization and industrialization.

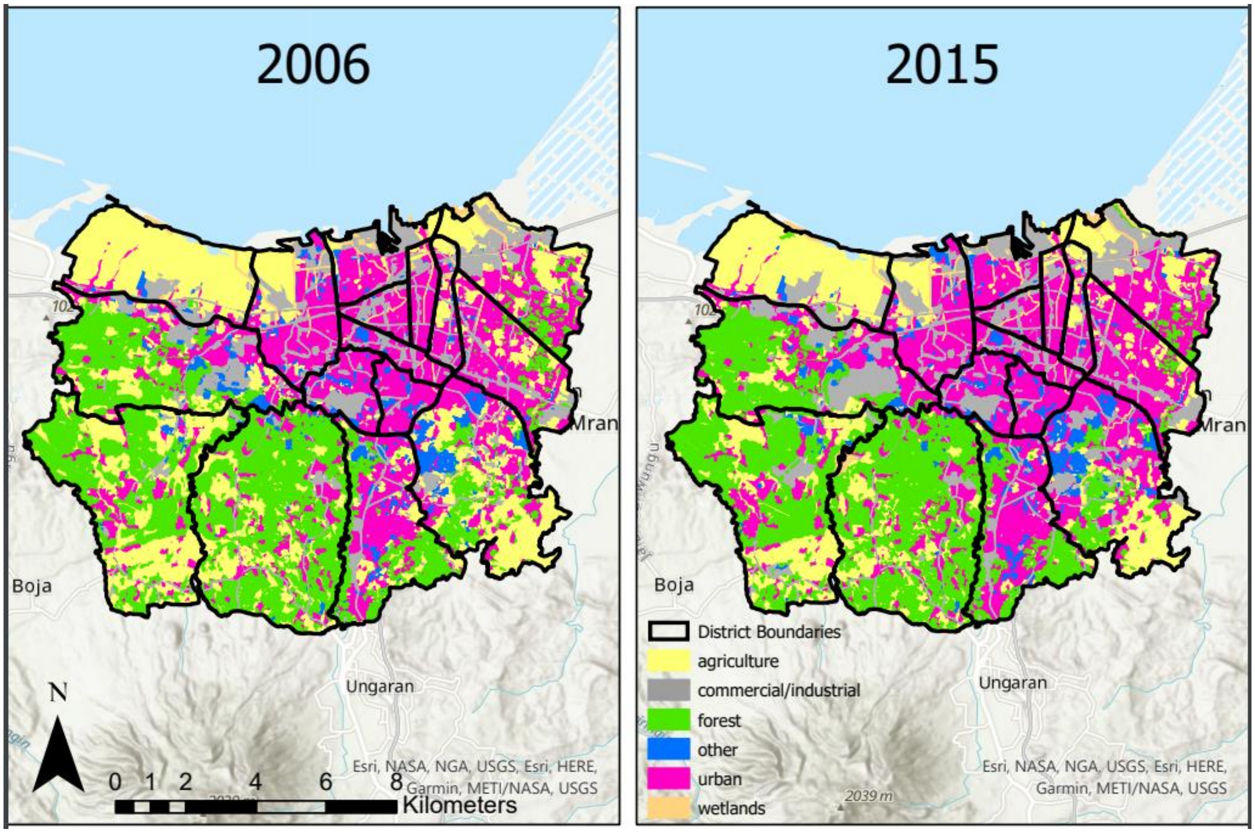

Figure 2. LULC in study area in 2006 and 2015, respectively

We utilized two World Bank LULC maps of Semarang City, Indonesia created by Earth Observation for Sustainable Development (eo4sd) by the European Space Agency (ESA) for 2006 and 2015 (ESA, 2021; Figure 2). The 2006 data was collected using Landsat-5, and the 2015 data was collected using Sentinel-2 (ESA, 2021). The raw data from ESA was divided into several different subsets ranging from general groups with 5 classes to the most specified LULC with 22 classes. We initially chose to focus on seventeen classes. However, this number of classes was not feasible, due to the extent of analysis and validation methods using Google Earth imagery.

Table 1. Matrix of Changes by NL_3 Classification in km^2; bolded are changes larger than 1 km^2

		Class in 2015																
		agriculture	airport	cemetery	construction	continuous urban	discontinuous urban	forest	green urban area	industrial	inland water	land without use	mining/dumping	other	port	recreation	roads/rails	wetland
Class in 2006	agriculture	null	0.841	0.004	**2.683**	0.304	**8.319**	**10.092**	0.774	**3.604**	**1.485**	**1.456**	0.495	**1.509**	0.000	0.076	0.133	0.090
	airport	0.000	null	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	cemetery	0.000	0.000	null	0.000	0.000	0.054	0.000	0.013	0.000	0.000	0.006	0.000	0.000	0.000	0.000	0.001	0.000
	construction	0.042	0.000	0.000	null	0.128	**1.606**	0.057	0.070	**1.483**	0.000	0.037	0.000	0.000	0.018	0.050	0.001	0.023
	continuous urban	0.000	0.000	0.000	0.000	null	**1.920**	0.000	0.006	0.000	0.000	0.005	0.000	0.000	0.000	0.000	0.003	0.000
	discontinuous urban	0.000	0.000	0.000	0.007	5.131	null	0.041	0.000	0.094	0.000	0.010	0.000	0.000	0.000	0.000	0.054	0.000
	forest	**2.298**	0.000	0.000	**1.108**	0.028	**7.809**	null	0.370	**1.150**	0.142	0.475	0.075	0.427	0.000	0.008	0.205	0.003
	green urban area	0.018	0.000	0.000	0.108	0.049	0.739	0.000	null	0.294	0.101	0.014	0.004	0.093	0.000	0.000	0.025	0.000
	industrial	0.052	0.000	0.000	0.126	0.000	0.000	0.019	0.049	null	0.000	0.000	0.000	0.010	0.000	0.000	0.011	0.000
	inland water	0.151	0.000	0.000	0.021	0.000	0.000	0.036	0.006	0.041	null	0.003	0.000	0.004	0.006	0.000	0.003	0.024
	land without use	0.006	0.000	0.000	0.128	0.007	0.100	0.114	0.148	0.453	0.000	null	0.000	0.269	0.023	0.007	0.000	0.000
	mining/dumping	0.000	0.000	0.000	0.036	0.000	0.046	0.004	0.007	0.000	0.000	0.055	null	0.000	0.000	0.000	0.000	0.000
	other	0.083	0.000	0.000	0.259	0.018	0.758	0.503	0.013	1.631	0.012	0.305	0.128	null	0.000	0.019	0.036	0.000
	port	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.022	0.000	0.000	0.000	null	0.000	0.000	0.000
	recreation	0.000	0.000	0.000	0.009	0.000	0.088	0.000	0.057	0.033	0.000	0.000	0.000	0.005	0.000	null	0.000	0.000
	roads/rails	0.000	0.000	0.000	0.012	0.000	0.005	0.002	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	null	0.000
	wetland	0.174	0.000	0.000	0.026	0.000	0.055	0.000	0.004	0.676	0.148	0.061	0.000	0.043	0.014	0.000	0.008	null

To familiarize ourselves with the data and understand the changes that occurred in Semarang City, we began by conducting a map of overlay analysis in ArcGIS Pro. The goal of this overlay analysis was to determine the landcover change between 2006 and 2015 in the seventeen selected classes. The results of the change matrix created from this overlay analysis helped to determine the reclassification we created (Table 1). This many classes was unmanageable due to the many combinations of change classes between 2006 and 2015. Moreover, some change classes may be too small and thus hard to validate.

Table 2. Reclassification to Simplified Classes

original class	reclassification
agriculture	agriculture
forest	forest
cemetery	other (natural/semi-natural)
green urban area	
other	
recreation	
inland water	wetland
wetland	
continuous urban	urban
discontinuous urban	
construction	industrial/commercial
airport	
industrial	
land wo use	
minin.dumping	
port	
roads/rails	

After further examination, we selected six classes, or 23 change classes, which better explained changes that occurred in Semarang over this period of time (Table 2). We then conducted a second overlay analysis of this subset data and created another change matrix. We ran two different accuracy assessments of this data: the first based on a traditional validation utilizing Google Earth Pro imagery, and the second based on photography and expert validation of the changing landscape of Semarang City. This overlay analysis told us which changes had occurred; however, further analysis was needed to determine where these changes were occurring.

An optimized hotspot analysis is used to show areas that are more likely or less likely to experience changes due to their location and whether or not their neighbors experienced change. To do this, we returned to a dataset which included all the data, not just the areas which experienced change but instead the original ESA dataset. We created a binary field where a 0 indicated an area with no change between 2006 and 2015 and a 1 indicating that a change had occurred as defined by our reclassification.

This ArcGIS analysis helped explain what had changes in 2006 and 2015 individually but not what had changes *between* 2006 and 2015. To answer this question, we turned to Google Earth Engine (GEE). We used a Continuous Change Detection and Classification (CCDC) (Zhu and Woodcock, 2014; Arevalo et al., 2020). A CCDC provides a plethora of data, from time-series plots for individual points, to rasters detailing the year a change most recently occurred and the number of changes which occurred in that area over a set time period. We imported a shapefile that represented the areas that experienced changes according to the aforementioned overlay analysis from our reclassified data.

Additionally, we wanted to gather data on the change in area cover of permeable surfaces in Semarang. To do this, we reclassified agriculture, forest, other, and wetland as permeable, and urban and commercial/industrial as impermeable. Finally, we used Google Earth Pro and Google Maps Street View with their time features to determine if rubber plantations were being run as rubber monocultures or rubber agroforestry (RAF) and to validate our Google Earth Engine results for when they were planted.

RESULTS

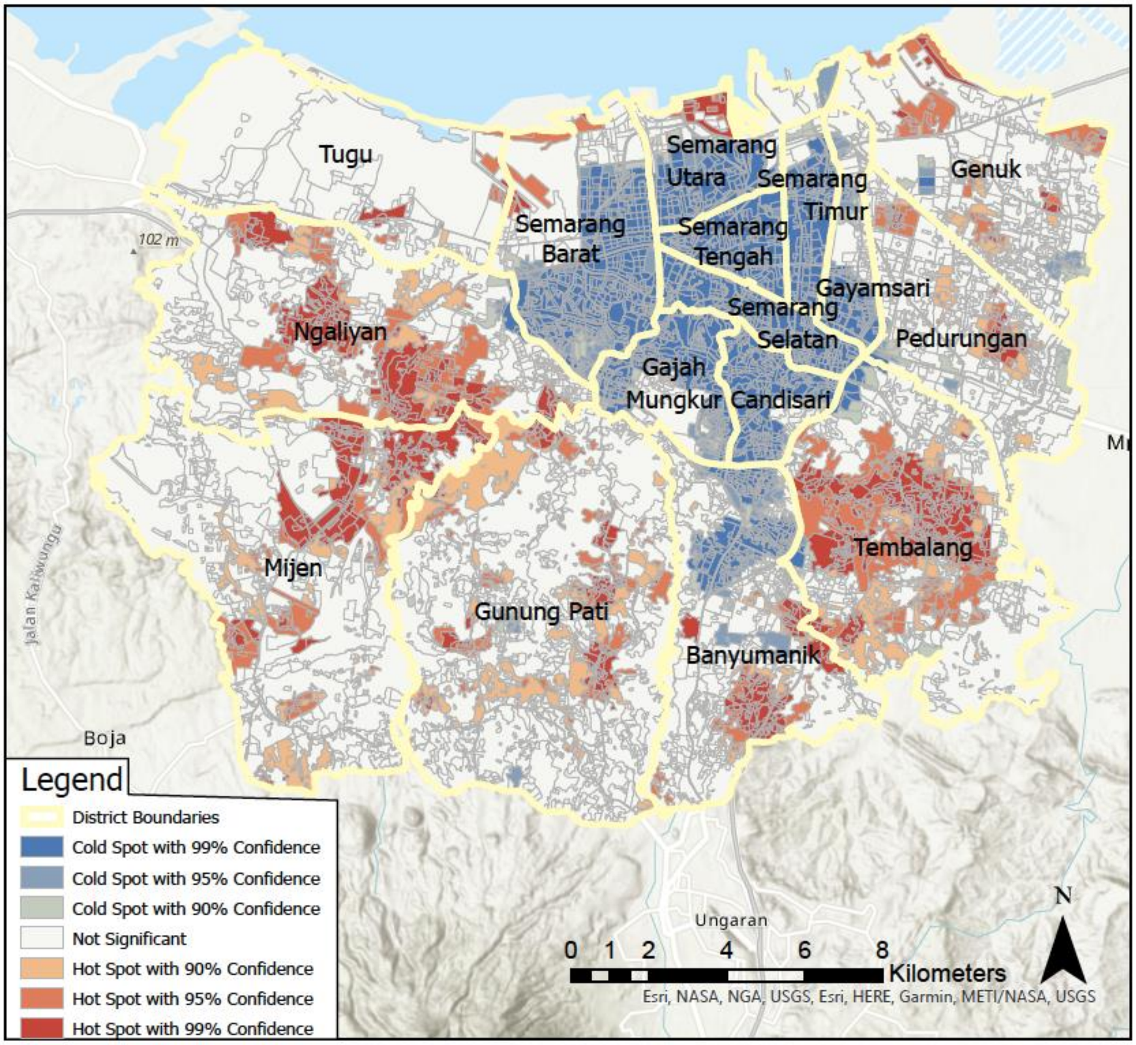

Figure 3. Optimized Hot Spot Analysis of areas likely to experience change in Semarang City, Indonesia

Areas that experienced change between 2006 and 2015 ranged throughout Semarang City, Indonesia as seen from the optimized hotspot analysis (Figure 3). There were almost no changes in the already developed districts of Semarang Tengah (Central Semarang), Semarang Selatan (South Semarang), Semarang Timur (East Semarang), Candisari, and Gajah Mungkur (Figure 3). The few changes in these areas changed from a class called *Other* to *Urban* or from *Other* to *Commercial/Industrial*. Upon inspection, these “other” areas in question were recreational or just general green areas in what appeared to be wealthier neighborhoods. Outside of these areas, there are quite a lot of changes over this decadal time period of observation. Between 2006 and 2015, 55.58 km^2 changed their classes, approximately 14.4% of the entire area of Semarang City.

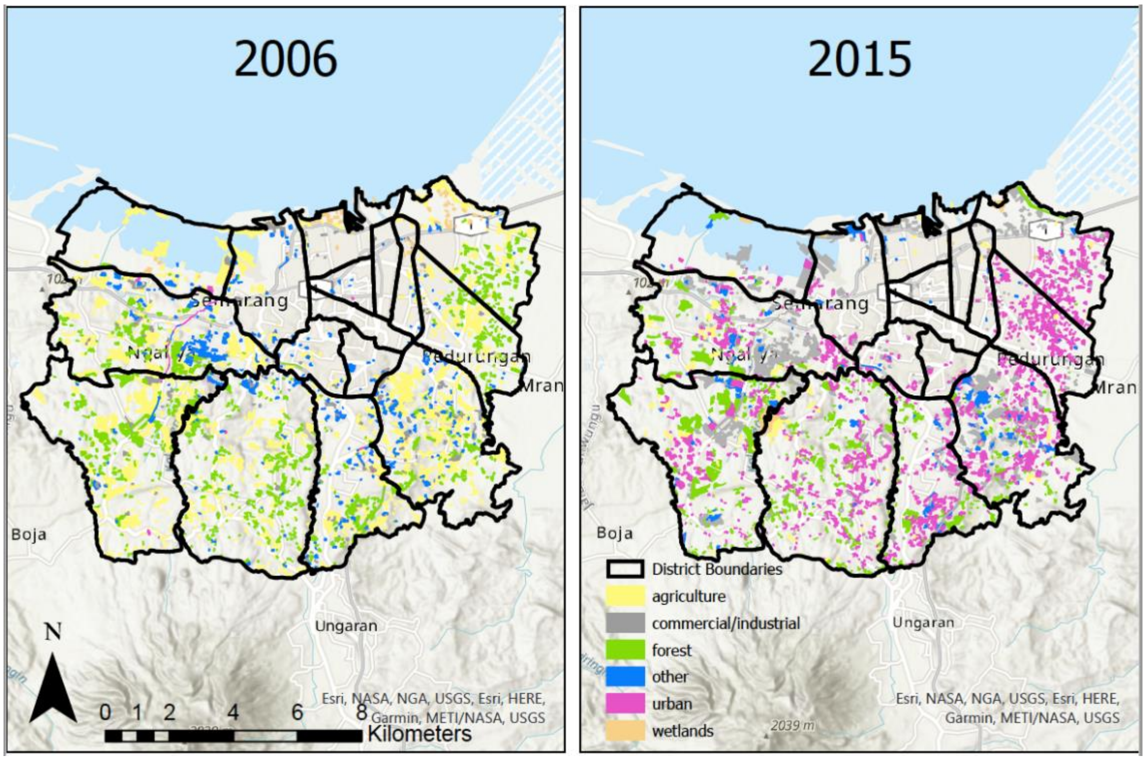

Figure 4. Areas of LULCC in Semarang; classes for each of the two years are highlighted

In 2006, many of the areas that experienced change were predominantly agriculture or forest (Figure 4). In the 2015 data, there is a clear loss in agricultural land; however, there were quite a lot of new areas classified as forest. Google Earth Pro imagery and expert analysis confirmed that these areas did transition from agriculture to forest in those years. However, this is not a return to nature but actually an increase in rubber plantations. Rubber plantations are composed of trees but lack the soil composition and biodiversity of flora and fauna found in forests untouched by humans (Penot, 2004). Because this data appears to be based more strongly around land cover rather than land use, this distinction was not made at any of the levels of specificity from the ESA dataset.

Table 3. Area change (km^2) between 2006 and 2015

		Class in 2015					
		agriculture	forest	commercial/industrial	other	urban	wetland
Class in 2006	agriculture	73.04	10.10	9.22	2.36	8.63	1.55
	forest	2.22	80.32	2.97	0.80	7.84	0.15
	commercial/industrial	0.15	0.19	44.08	0.68	1.89	0.04
	other	0.10	0.50	2.85	10.96	1.71	0.11
	urban	0.00	0.04	0.17	0.01	117.24	0.00
	wetland	0.22	0.04	0.89	0.06	0.06	3.52

Many of these new rubber plantations appear in the Mijen district, the district in Semarang with the highest number of farmers (Wiraguna and Putra, 2016). Mijen is approximately 53.85 km^2 making it the second largest district in Semarang. In 2006, 18.65km^2 was agricultural land, roughly 35% of the area. Between 2006 and 2015, a third of that land was converted from agricultural land with more than half of that (3.80 km^2) being converted into forest. Throughout Semarang, which has an area of approximately 384.75 km^2, 31.86 km^2 of agricultural land in 2006 was converted. Thus approximately 8% of all land in Semarang was converted from agriculture, while only 10.10 km^2 of that 31.86 km^2 was converted from agricultural land to forest. Hence, the 3.80 km^2 change in Mijen is relatively high for its area size. In conclusion, even though there is not a higher rate of agricultural land being transformed to another class in Mijen, there is a much higher rate of agricultural land being transitioned to forest than in other parts of Semarang (7.63% for Mijen versus 2.63% for Semarang).

Tembalang District also had a lot of agricultural areas (roughly 6.47 km^2) in 2006 which did not exist as agriculture in 2015. However, most of the land in this area was changed into commercial/industrial (2.67 km^2) or urban classes (2.20 km^2), at 6.44% and 5.30% respectively of the total land area in Tembalang. As in Mijen, this was a higher rate of change than was seen in the city at large. In all of Semarang, there was a total of 16.11 km^2 (4.19% total area) changes to commercial/industrial and 20.13 km^2 (5.23% total area) to urban regardless of original class in 2006.

Between 2006 and 2015, Semarang saw a decrease of roughly 33.05 km^2 in permeable surfaces. That is equivalent to about 10% of the land cover in all of Semarang. In 2015, the majority of the city was covered in impermeable surfaces, approximately 65.83%.

Figure 5. Number of Changes in areas with LULCC; darker reds indicate more changes

As mentioned in the Methods section, the ESA dataset helped explain what the LULC was in 2006 and 2015 but not what had occurred in these areas *between* 2006 and 2015. The GEE CCDC helps explain what happened in the interim. The areas that had LULCC according to the GIS dataset experienced a range from one to four changes between 2006 and 2015 (Figure 5).

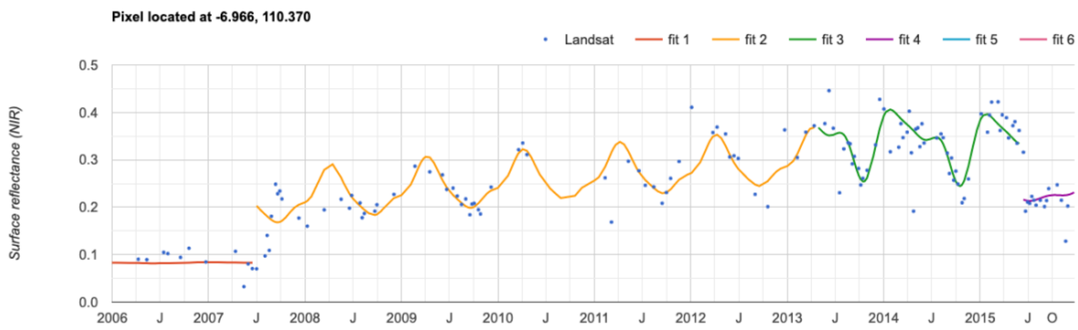

Figure 6. Sample CCDC of Semarang's airport

One of the areas that experienced many changes is at the border of the Tugu district and Semarang Barat (West Semarang) where the Jenderal Ahmad Yani International Airport was expanded (Figure 5). CCDC detects changes in the pattern of Surface Reflectance (Near Infrared) over the course of time. Between 2006 and 2015, there were four pattern changes detected at the airport with those changes occurring in the summer of 2007, in the spring of 2013, and in the summer of 2015 (Figure 6). In 2006, the area the airport would occupy was classified as agriculture. Using Landsat imagery, the land can be seen changing from aquaculture to dried land to construction to the airport.

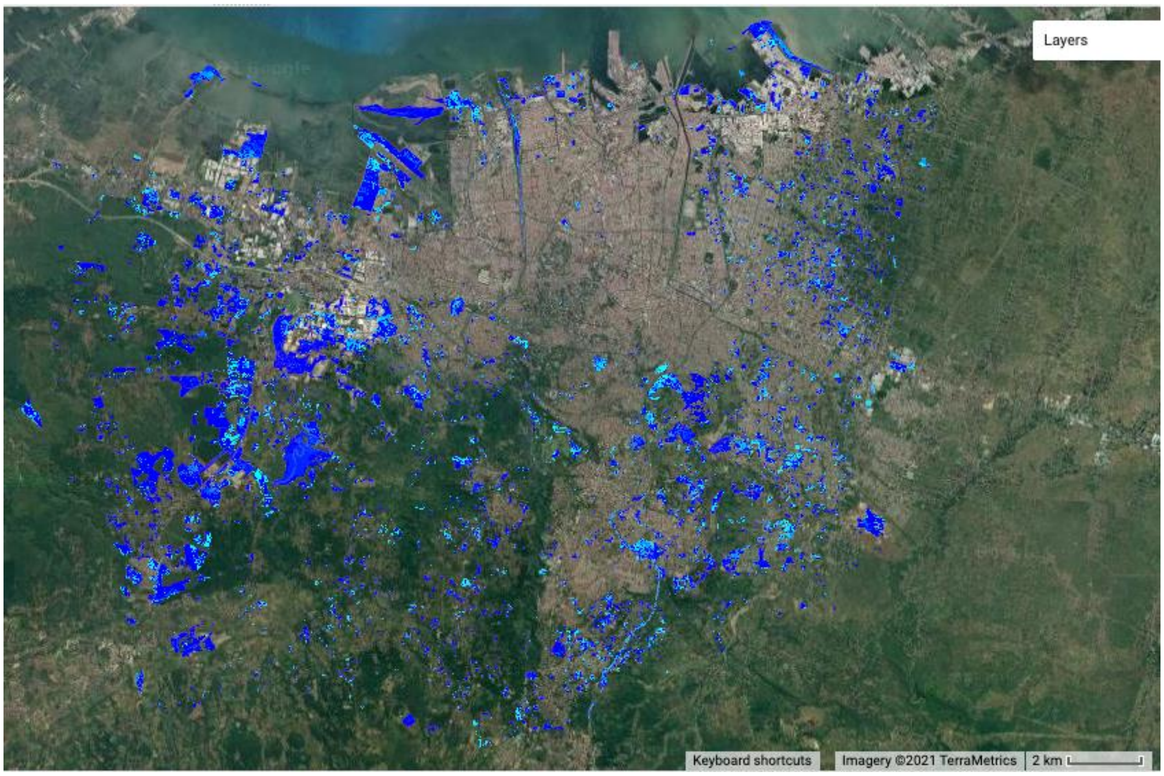

Figure 7. Year of Last Change in LULCC Areas; darker blues indicate more recent years (2014, 2015)

Other areas like in Pedurungan, which predominantly changed from forest and agriculture to urban, only experienced one or two CCDC changes during the period of 2006 to 2015. These ranged in years based on when an area transitioned from either forest or agriculture to the homes, offices, and other buildings of the urban fabric (Figure 7).

Areas in Mijen which were converted from agriculture to forest also went through a higher number of CCDC changes. This is indicative not only of the planting and growth of the rubber trees in this area, but also what appears to be a change in the type of agriculture grown during the agricultural period.

Figure 8. Sample of Rubber Agroforestry (left; location: 7°01'55.5"S 110°24'23.6"E) and Rubber Monoculture (right; location: 7°01'12.9"S 110°19'49.5"E); images from Google Map Street View collected April 2015 and March 2015, respectively.

By observing a sample of the areas that were converted from agriculture to forest, we were able to determine that most of these forests appeared to be planted between 2008 and 2011. Additionally, using Google Maps Street View, it became clear that the rubber plantations are actually a mix of Rubber Agroforestry (RAF) and traditional monoculture (Figure 8). In the example from Figure 8, the RAF image shows a banana tree on the left side as well as what appears to be another crop as groundcover. Both of these rubber plantations are on the younger side as seen by the small trees and the lack of sap harvesting marks on the trunks (Figure 8). Additionally, they each have heavy undergrowth (Figure 8).

DISCUSSION

Between 2006 and 2015, there were many LULLC in Semarang City, Indonesia. In this period of time, Semarang lost 31.85 km^2 of agriculture land and 14.00 km^2 of forest land and gained 20.13 km^2 of urban land and 16.11 km^2 of commercial/industrial land. These changes are indicative of economic growth and increased infrastructure. However, there was also a loss of 33.05 km^2 of permeable sediments.

Implications of Increased Rubber Plantations

A sixth of the agricultural land in Mijen in 2006 was converted to forest lands by 2015. Of these new "forests", the majority are rubber plantations. This incredibly high turnover indicates an economic change. Rubber is a cash crop that also offers farmers the opportunity for sustenance farming in the understory. This change in Semarang is indicative of a larger transition in Indonesia.

Historically, Indonesian farming was a combination of traditional terrestrial agriculture and aquaculture in tidal waters and mangrove forests. However, Indonesia is now seeing an increase in commercial agriculture, particularly rubber monocultures and Rubber Agroforestry (RAF) (Penot, 2004). RAFs have the added benefit of not only producing a cash crop—rubber—but also providing food for local farmers by growing fruit trees, such as bananas, or crops, such as highland rice, beneath the rubber's canopy (Penot, 2004). Although this results in slower growth of the rubber trees, and thus an increased wait time before harvest, the benefits of RAFs cannot be ignored (Penot, 2004).

The changes in Mijen, from traditional agriculture to rubber forests, are an indicator of an increase in economic opportunity for individual farmers in this region. As Mijen has the largest number of farmers of any district, the increase in rubber plantations, a profitable cash crop, may mean an increase in wages and better livelihood for the people of Mijen (Wiraguna and Pratama, 2016). Furthermore, the presence of Rubber Agroforestry (RAF) in Meijin suggests increased sustainability, not just for the flora and fauna of the forest but for the people themselves. As aforementioned, RAF is not solely the practice of maintaining a monoculture of rubber, but also of planting other trees and vegetation. Thus, in addition to the economic benefit of money there is also the added benefit of providing local produce to farmers and communities.

Additionally, rubber is an economically important export to Indonesia. This increase in economic growth often shadows an increase in welfare throughout developing nations like Indonesia (Daulika et al., 2020). The increase in rubber plantations in Semarang not only benefits farmers but also Indonesians and Indonesia as a whole.

However, rubber plantations do have downsides, particularly in regards to ecology and biodiversity. Indonesia is a land full of nutrient rich volcanic soil (Daulika et al., 2020). However, agriculture, particularly monoculture, is a nutrient suck that would remove nitrogen and other important compounds from the earth (Ahrends et al., 2015). Additionally, rubber plantations have a high likelihood of failure from climate disasters such as droughts and typhoons (Ahrends et al., 2015). Finally, the clearing of land to create rubber plantations leads to the loss of conservation critical biodiverse areas (Ahrends et al., 2015). This may be less relevant in areas where these rubber plantations have been planted in lieu of agriculture but our model does not account for areas that have transitioned from "natural" forest to rubber plantation. It is likely that this transition did occur and thus should be accounted for in some measure in this study.

The consequences of increasing rubber plantations bridge the controversy of the UN SDGs. The increased profits from rubber plantations benefit both farmers and

Indonesia as a whole; the latter fulfills the SDG call for increased GDP for developing nations (8.1) and the former builds resiliency among the poor (1.5; UN, 2015). Additionally, in the case of RAFs, local farmers are able to both increase "agricultural productivity and incomes of small-scale food producers" (2.3) and "ensure sustainable food production systems" (2.4; UN, 2015). However the loss of biodiversity and the degradation brought about by the loss of forests and increase in rubber plantations directly go against the UN SDG (15.5; UN, 2015). These goals are at odds with one another and thus require closer examination.

Spread of Suburbia

In Tembalang district, there was a transition from agriculture to commercial, industrial, and urban areas. The uptick in suburban housing and economy in Tembalang is an indicator of how the urban planning of Semarang as a whole is developing. Semarang's population has burgeoned in recent years (UN, 2019). With this increase in population there needs to be an increase in economic opportunities and safe, affordable housing for these individuals. These align with guidelines eight and nine of the United Nations Sustainable Development Goals which highlight the need for decent work and economic growth and industry, innovation, and infrastructure, respectively (UN, 2015).

The spread of suburbia does not just mark an increase in economic growth and infrastructure but also a decrease in ecosystem services. Urban sprawl is often not the same as population growth meaning that frequently more areas are developed than is absolutely necessary (Yuan et al., 2019). The resulting loss of ecosystem services directly violates the

UN SDGs which call not only for protecting ecosystems but for making them even stronger and more prevalent (15; UN, 2015).

Additionally, the loss of agriculture, forest, wetlands, and other greenspaces means the loss of permeable surfaces. Semarang City is prone to subsidence due to increase in the weight of the new infrastructure and the extraction of groundwater from the aquifer (Abidin et al., 2012). The loss of permeable surfaces means that the aquifer cannot replenish on its own (Abidin et al., 2012). Thus local people, who get most of their water from wells, may lose access to clean water as a result of the decrease in permeable surfaces and increase in urban and commercial/industrial zones. This directly violates the sixth SDG of the UN, namely that people have access to clean water and sanitation (UN, 2015).

Concerns about ESA Dataset

There are several issues with this ESA dataset including that it was only run in two years and the lack of differentiation between agriculture and aquaculture. Aquaculture is very prevalent in Semarang City especially in coastal regions of the city. It would have been interesting to see if as a result of subsidence and salt water encroachment, more inland areas that were previously agriculture became aquaculture. Additionally, with more classification, I could observe if these inundated areas of aquaculture transitioned to other since they may no longer be desirable for farming of any kind.

The presence of only two years of data means that there is an inability to validate. That is, do our expectations and findings of what occurred between 2006 and 2015 apply into the future? Granted it has not yet been nine years since 2015 but there is still a possibility that further expansion would be visible both in regards to urbanization and increases in rubber plantations.

A final issue with this data source was that its focus was much more heavily on land cover than on land use. We can see this in their classification of forests as being a forest regardless of its use as a cash crop or as a natural green area. This influences the sustainability of Semarang City in regards to the UN SDG about life on land which concerns not only the loss of biodiversity but also the importance of sustainably managed forests (UN, 2015).

CONCLUSIONS

Remote sensing and new technologies have increased the access we as researchers have to observing LULCC. This sort of analysis was previously insolvable; our ability to now create comprehensive studies spanning decades and swaths of land enables us to explore the transitions of LULCC over time as seen in our GEE CCDC analysis. Furthermore, the ability to combine GIS and remote sensing data allows not only validation but also a further depth and breadth of knowledge. This yields promising results that can be implemented not only to study Semarang but in a range of developing cities and countries. This analysis allows for a way to conclusively determine how these areas are achieving the UN SDGs.

In Semarang City, policies could be utilized to ensure that future development is inline with some of the UN SDGs. As aforementioned, these goals are highly conflicting. Our first recommendation is to cease the removal of non-crop forest and to prevent “wild” forest to be converted to rubber plantations. This would essentially be a halt to deforestation

(15.2; UN, 2015). Additionally, as a result of LULCC there is a need to increase forested area potentially using similar technologies to those in this study (15.3; UN, 2015; Nurda et al., 2020). Population is expected to continue to increase in Indonesia and, as such, urban sprawl is likely to progress (UN, 2019; Yuan et al., 2019). To properly create sustainable urban planning and development, this study could be expanded to create models for potential urban growth and spread (Achmad et al., 2021). Models in other parts of Indonesia suggest that, in general, decreasing urban sprawl, specifically urban fragmentation, maintains vegetated areas and consolidates sustainable infrastructure (Achmad et al., 2021; Wahyudi et al., 2018). Thus we recommend a policy of consolidation; that is, instead of allowing the slow spread of suburbia into less developed portions of Semarang City, using zoning to limit habitation to currently urbanized areas. By increasing density, there would also be a decrease in transportation infrastructure allowing more resources to be put into these settled areas instead of spreading them out (9.4; UN, 2015). However, there is still the need to have a growing GDP (8.1; UN, 2015). Due to the limitations of land use the need to increase economic growth must occur in sectors of industry that are not heavily land dependent. These include such things as fishing and tourism. By increasing funding to these sectors and encouraging growth there, individuals would be able to increase their “technical and vocational skills” (4.4) and provide “productive employment” (8.5; UN, 2015).

These initiatives are potentially applicable around the globe in developing communities and in those dealing with the trials of extreme weather and climate change. There is a need to further examine the conundrum that is the UN SDGs conflicts. However, tools provided by remote sensing and geospatial analysis offer ways to better assess and implement policies for the future. By looking back at LULCC that have already occurred, we not only have a glimpse into the future with a business-as-usual strategy, but also can see other alternatives should we choose to implement even one of the aforementioned policies.

APPENDIX A

GEE code can be viewed at this link:
https://code.earthengine.google.com/8b80b591aaab91c4b20f6d5308aefb6a

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