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Integrating Remote Sensing Images and Public Administrative Data for Monitoring Deforestation of Tropical Peatland.

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Abstract
A comprehensive tropical peatland monitoring is a crucial factor for the preservation of tropical peatland in Indonesia. However, existing approaches in the tropical peatland monitoring much emphasized on biophysical aspects while neglecting human factors of the deforestation. Therefore, this research is aimed at developing an integrative method for monitoring tropical peatland deforestation in which biophysical aspects and human-socio factors are both assessed. Remote Sensing (RS) Images and Public Administrative Data (PAD) are used as data sources. However, challenges exist in both RS analysis and PAD analysis. As a tool for biophysical assessment, current RS techniques for monitoring artificial waterways (AW), human made structures such as canals and ditches, are less studied, particularly for traditionally built canals which usually very small in size. Pixel-based RS may not really appropriate to do so. A Geographic Object-Based Image Analysis (GEOBIA) is more appropriate. Meanwhile, for monitoring human factors of deforestation, PAD analysis requires appropriate base maps as a geocoding tool to spatially analyse the data. Therefore, this study develop a framework in which biophysical aspects and human factors are assessed simultaneously for a comprehensive tropical peatland monitoring. Land cover change and AW development are target of the assessment. They are indicators of human interference to the tropical peatland. For land cover changes, assessment is conducted using supervised classification with Landsat images as the main data source. Meanwhile, for AW detection, integration of local knowledge and image processing is applied in a GEOBIA approach of RS analysis. Further, in order to understand human factor behind the AW developement, the result of detection is integrated with PAD using RT (Rukun Tetangga/Neighborhood Association) as spatial key. For the purpose, RT Base Map (RTBM) is developed using village sketch maps of population census. However, typical sketch maps problems including distortion, schematization, and incompleteness add more challenges to the boundary uncertainty issue in the development of RTBM. To solve the issues, RT is plotted from the sketch map. In order to make it possible to play as a linker for geocoding though uncertain in the boundary, the RT is separated as point (landmark, centroid), line (rivers, roads), area (boundary) before georegistered as a new base map. Further, a data model is developed to build the RTBM before using it as a geodocing tool. After an accuracy assessment, it was found that the procedure can improve the base map accuracy from 49 percent as of direct digitization to be 75 percent. As a case study, this research scrutinized Sebubus Forest in West Kalimantan Province, Indonesia.
Landsat image classification shows that around 80% of total 14.501 Ha of Sebubus Forest was still covered by forest in 1995, during which data from local government indicates it was relatively free from AW. Rapid increase of deforestation found in 2009 and 2013 in which the bare land reached 22.5 percent and 35 percent respectively. In consequence, by 2016, only 11.56 % of total area remained forest. Furthermore, using new GEOBIA technique, 22 new canal systems were detected in 2009, mostly in villages of the western side of the forest. On average, there have been 20.81 km or 8 new AW systems developed in Sebubus Forest every year from 2009 until mid of 2017. In 2014, primary canals went across the peat dome area. As of 2015, the primary canals were completely crossing the forest from the west to the east. In 2017, the AW's networks have totally covered the forest. On the other hand, using GIS advantages, PAD analysis shows that the geographical patterns of land cover changes and AWs development were in line with the patterns of population distribution and demographic attributes. In 2005, some activities slowly infiltrated into the forest. By 2009, huge deforestation detected on the northern edge of the forest in which bare land increased from 179 Ha to be 3.267 Ha. The significant increase was mostly related to 3 villages in Jawai Sub District named Sarang Burung Danau, Sei Nilam, and Sarang Burung Kolam. From the villages, PAD analysis found that, the centroids of RT boundary

disperse evenly and line up towards the forest from the west. In contrary, RT centroids tends to be clustered in villages of eastern side. Poor people were found between 72-129 people in RTs proximate to the deforested area compared to only 10-43 people in distant RTs. Another data shows that from 11 villages in the western part where high rate of deforestation happened, number of poor household were found between 130 until 325 families per village, much higher than 25 to 129 in 10 villages of less deforested side of the forest. From land tax databases, it was found that number of land tax registration in RTs of western side was very few in 1999 compared to more than 300 per RT in villages of eastern part. However, the number rose sharply in 2011 when land tax registration in RTs of villages of western side was 14-345 per RT.
In summary, this dissertation presents an original works for an integrative tropical peatland monitoring in which biophysical aspects and human factors behind the deforestation are assessed through RS images and PAD analysis. While, RS analysis successfully clarify the states and stages of the deforestation, PAD are used for retrieving the involvements of communities. The integrative approach is a systematic understanding of the deforestation in the tropical peatland in wich AW found playing a key role in the progress. It also successfully detected the AW in place and trace out the possible social entities involved in the development. Key components of the integrative approach are the GEOBIA and RTBM as a geocoding tool. Limitation of this study is that it is tested in one case study only, therefore, some modification is certainly needed for wider use in vast tropical peatland area. However, the core components and main ideas should remain applicable. Finally, it can be concluded that the framework and methods can enrich existing literature as well as contribute to the improvement of current tropical peatland conservation in Indonesia.Practically it can used to stop new projects of AW development in the tropical forest. More over, the procedure of RTBM Development could be a model for developing a new layer of Indonesia NSDI. While, the data sources of this thesis is prevalent and accessible for local governments in Indonesia, it can be used to enhance policy recommendation for specific target of poor RT for effective and efficient social development policy.

Keywords: Tropical peatland, Remote Sensing, Public Administrative Data, Deforestation.

Preface

In the name of God, the merciful and compassionate. All praises be to Him, the creator of the earth and the heaven, who taught by the pen. Taught man which he knew not. All of the work presented henceforth was conducted during my term as a PhD student at Eco GIS Laboratory, Graduate School of Media and Governance, Keio University Shonan Fujisawa Campus.

A version of Chapter 4.1 has been published as a conference paper [Muriadi, & Yan, W. L. (2017). Land cover changes from 1995 to 2016 in sebubus forest of sambas regency, Indonesia. In *Proceedings-2016 International Electronics Symposium, IES 2016*. https://doi.org/10.1109/ELECSYM.2016.7861033]. Meanwhile, a version of Chapter 4.2 has been published as a journal paper [Arip, M., & Wanglin, Y. (2019, April 3). Monitoring AWs in Peat Forest Areas Using Geobia (GEOBIA) Method: Case Study in Sebubus Forest, West Kalimantan. *Jurnal Borneo Administrator*, *15*(1), 99-116. https://doi.org/https://doi.org/10.24258/jba.v15i1.420]. I was the lead investigator, author, and presenter for the papers, responsible for all major areas of concept formation, data collection and analysis, as well as manuscript composition. Professor Wanglin Yan was the supervisory author on these works and was involved throughout the project in concept formation and manuscript composition. He and Dr. Kazuyo Hirose also played the same role for third papers which is a published version of Chapter 5 and 6 [Muriadi Arip, Wanglin Yan, and Kazuyo Hirose. (2019). Using neighborhood association area as new spatial data infrastructure to link public administrative data with GIS in Indonesia. Communications in Science and Technology, 4(1), 20-29. https://doi.org/10.21924/cst.4.1.2019.111]. Professor Lynn Thiesmeyer and Professor Tomohir Ichinose supervised this dissertation thoroughly. Finally, thanks also to Professor Yasushi Kiyoki for his comments for improvement of this dissertation so that this dissertation reaches its final scientific form.

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Abu Kaysan, Muriadi bin Muhammad Arip bin Abdul Ghani bin Abdul Razak bin Kulud

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Abbreviations and acronyms:

AW	: Artificial Waterway
GE	: Google Earth
GEHRI	: Google Earth High Resolution Imagery
GEOBIA	: GEOBIA
GIS	: Geographical Information System
Gt	: Gigaton
IPCC	: Intergovernmental Panel on Climate Change
ISDI	: Indonesia Spatial Data Infrastructure
NSDI	: National Spatial Data Infrastructure
NW	: Natural Waterway
OBIA	: Object-Based Image Analysis
PAD	: Public Administrative Data.
RS	: Remote Sensing
RT	: Rukun Tetangga (Neighborhood Association)
RTBM	: Rukun Tetangga (Neighborhood Association) Base Map
SABBM	: Smallest Administrative Boundary Base Map
SDI	: Spatial Data Infrastructure

Glossary

Artificial Waterway: Human made construction to channel the flow of water from one place to another usually for drainage purposes such as canal, ditches, and also pond where water from its surrounding collected for any purposes.
Base Map: map used as the platform for processing spatial data in developing/making a new (thematic) map.
Deforestation: biophysical change of forest that degraded its natural ecosystem's function.
Digitization: conversion of non-digital map into digital geodatabase using computer (GIS) application
GIS: a computer system used to capture, store, manage, analyze, manipulate, and visualize geographical data.
Monitoring: systematic activity to observe event, occurrence, or progress of something
Natural Waterway: A natural earth structure that channel the water to flow from one place to another.
Object-Based Image Analysis: a method of image analysis in which similar pixels in an image are grouped to identify or classify objects.
Peatland: a type of soil on the surface consisting mostly of partially decomposed vegetation with certain

amount of organic matter content.

Pixel-Based Image Analysis: a method of image analysis in which objects are identified/classified based on value of pixels in an image.

Public Administrative Data: data produced by public institution as a result of administrative affairs and usually aimed for service delivery purposes.

Remote Sensing Analysis: analysis using image obtained from distant such as satellite or airborne

Remote Sensing Image: image obtained from distant such as satellite or airborne

Rukun Tetangga Base Map: a set of spatial data containing neighborhood association administrative boundary/components that can be used as a platform for developing/making a map.

Rukun Tetangga: Neighborhood Association, a group of households within spesific neighborhood area.

SDI: hardware, software, policies, resources, and framework required to acquire, process, use, maintain, preserve, and present spatial data.

Smallest Administrative Unit: the smallest administrative entity that has administrative boundary as a tool to organize population or object within the area.

Spatial Data: Data that can be associated to specific spatial/geographic reference

Tropical Peatland: peatland in the tropical hemisphere of the earth.

1. INTRODUCTION

1.1 Background

A comprehensive tropical peatland monitoring is a crucial factor for the preservation of the precious ecosystems in Indonesia. However, while the number of studies assessing the biophysical components of peatlands is growing, little attention has been given to evaluating the human drivers of peatland degradation, and further integrating them with biophysical research on peatland restoration and conservation activities (Medrilzam, Dargusch, Herbohn, & Smith, 2014). In fact, there is still very little comprehensive knowledge of the socio-economic, socio-cultural or socio-ecological aspects of tropical peatland ecosystems (Page, Rieley, & Wüst, 2006). Moreover, while much attention has been given by forest scientists on the employment and development of RS data for biophysical monitoring of tropical peatland, almost no attention has been given to potential use of big data such as of databases generated by government or public institution's daily service delivery. Based on situational awareness of aforementioned statements, this study explores a potentiality of integrating RS and PAD for monitoring deforestation in a production forest which is a tropical peat forest and the interactions between socio-cultural activities of local communities.

Peatlands in general, are important ecosystems for a wide range of wildlife habitats supporting important biological diversity and species at risk, freshwater quality and hydrological integrity, carbon storage and sequestration, and geochemical and palaeo archives (Joosten & Clarke, 2002). Meanwhile, tropical peatland is one of key ecosystems among the high-carbon reservoir ecosystems because of its effect on coastal ecosystems (Osaki & Tsuji, 2015). In addition, tropical peatlands are inseparably linked to social, economic and cultural values coexist with the environmental ecosystem.

In term of its function as carbon storage, ecological service, and biodiversity, tropical peatlands play a very important role globally and regionally. However, despite the importance and extensive attention from multi-stakeholders, misguided land use policies have resulted in widespread peatland degradation during the past 20 years (Dohong, Aziz, & Dargusch, 2017). Therefore, the reality of the management and conservation needs to be clarified. On the other hand, innovative efforts for preservation and sustainable management of the unique ecosystems should be continuously done.

Current study estimates that globally tropical peatland has a volume of around 88.6 gigaton carbon pool which is 15-19 % of total global peat carbon pool, and Indonesia has the largest share of tropical peat carbon which is estimated as many as 57.4 Gt (Page, Rieley, & Banks, 2011). From 441.025 km2 of the total world tropical peatland area, it is predicted around 14.91 million hectares spread over the archipelago country (Osaki, Nursyamsi, Noor, Wahyunto, & Segah, 2015; Page et al., 2011). The government of the country has trying hard to cope with the extreme pressures experienced by the tropical peat forests all over the country (Agus, Mulyani, Nurida, Ariani, & Widiastuti, 2017). Yet the reality of the management and conservation has never been fully clarified. The need for economic development often hardly be harmonized with ecological preservation. It is not a big surprise if the country experienced various adversities related to the unique ecosystem.

In fact, deforestation of the tropical peat forests has given some severe consequences. Repeating occurrences of huge forest fires, for example, resulted in regional scale smoke haze disasters. A study by Harvard Columbia University estimated that smoke haze from tropical peat fires mostly in Indonesia linked to more than 100.000 death in September-October 2006 (Koplitz et al., 2016). Another study indicated that peat fires mostly from Sumatra of Indonesia in June 2013 caused air condition in Singapore to reach an all-time record high that made the air of the country very unhealthy (Gaveau et al., 2014). Those are only small examples of consequences to be paid for a failed tropical peat forests management and conservation.

Management of tropical peatlands in Indonesia has a long history. The utilization of the unique soil has begun in the colonial era. It is mentioned that the first known method for tropical peatland in Indonesia is Handil Systems in 1920, then Anjir System in 1945-1960, Fork system and Comb system in 1969-1995, and then the largest scale utilization such as of famous Mega Rice Project in Central Kalimantan (Osaki & Nursyams, 2015). However, sustainable management for the utilization of the tropical peatland always in question. For instance, while many believe that current drainage-based agricultural activities in peatlands have no any negative impact on the environment, the other believes that current normally practiced management is not sustainable for tropical peatlands (Wijedasa et al., 2017). Therefore, more peat scientists argue that the actual debate should be focused no longer on how to develop drainage-based agriculture, but on whether the sustainable conversion to drainage-based systems is possible at all (Evers, Yule, Padfield, O'Reilly, & Varkkey, 2017). In this sense, the narrative which becomes the basis for the exploitation of tropical peatland in Indonesia that sustainable peatland utilization can be achieved by using drainage-based agriculture practices should be changed. Until new evidence says otherwise, sustainable peatland utilization should be confined in the narrative of preserving the pristine peat forest ecosystem. Moreover, monitoring the peat forests and the relationships with related communities should be enhanced.

Indonesia has launched several regulations for improving peat sustainability, including the suspension of new permits for peatland utilization and the formation of Peat Restoration Agency, mandated for restoring degraded peatland (Agus et al., 2017). National scale tropical peat forests management and policy can be helpful. However, as the interaction between forest and communities inside and surrounding the forests usually always unique depending on socio-cultural uniqueness of the communities, a uniform management system and policy may not really appropriate to be implemented.

Therefore, monitoring deforestation and its social roots can be one of the key factors determining the success of tropical peat management in the future. There is, however, still very little comprehensive knowledge of the socio-economic, socio-cultural or socio-ecological aspects of tropical peatland ecosystems (Page, Rieley, & Wüst, 2006). For such purpose, new methods capitalizing contemporary approaches and techniques such as of RS application which is interactively complemented with big social data are important.

There are several reasons why developing integrative methods for monitoring tropical peat forests is required. One of the reasons is that deforestation of tropical peat forest generally happened due to pressures from human activities inside or around the ecosystems (Brun et al., 2015). Therefore, seeing the deforestation merely on the ecological aspects may not much help to halt the increase. For example, RS can give clear picture of the loss of tropical peat canopy. But it hardly explains why do people cut the trees. On the other hand, detecting the loss of the forest itself may not really help, since it has happened. Meanwhile, seeing it from merely social aspects also hardly giving a clear picture of what really happened to the forest. For example, to draw precise lines and the stages based on deforestation on temporal sequence is hardly achieved unless using RS data, particularly in a large area.

The other reason is related to the importance of the reciprocal relationship between the communities and the tropical peatland. While people may the main actor of the tropical peatland deforestation, they can and always certainly be impacted by the adverse consequences. In this case, monitoring the adverse impact of the deforestation of tropical peatland is another benefit of the integrative approach.

1.2 Research Problems

1.2.1 Tropical peatland conservation problems

In Indonesia, peatlands have been utilized for agriculture since very long time ago. People in Kalimantan for instance, have cultivated various products on peatland for their food (rice, corn, sago, cassava), fruits (durian, rambutan, mango, etc.) and spices (Osaki, Nursyamsi, et al., 2015). Local communities have used them extensively for centuries with no significant effect on the environment (Boehm, H. -D. V., and Siegert, F., 2001). The problems began when the government implemented large scale projects without proper management systems. The expansion of commercial agriculture and other forms of economic development highly threatened large intact areas of tropical peatland (Roucoux et al., 2017). Many large-scale government projects and large-scale commercial plantations make the deforestation of tropical peatlands faster than other types of forest. For instance, while the average deforestation rate in Kalimantan (Borneo) was 1.7% per year, the rate of deforestation in peatland area is higher (2.2 %) (Langner, Miettinen, & Siegert, 2007; Miettinen, Shi, & Liew, 2011).

The area of industrial oil palm plantations in the peatlands of insular Southeast Asia (Malaysia and Indonesia, except the Papua Provinces) has increased drastically over the past 20 years with the 2010 extent of oil palm plantations on peatland may nearly double to 4.1 Mha by 2020 (Miettinen et al., 2012). Efforts by world community to halt the rate seems far from succeed. Certification on palm oil plantations operate in tropical peatlands area, for instance, so far had no causal impact on forest loss in peatlands (Carlson et al., 2017).

Conserving peatland on a landscape scale, with their hydrology intact, is of international conservation importance to preserve their distinctive biodiversity and ecosystems services and maintain their resilience to further environmental change (Roucoux et al., 2017). In fact, conserving peatland's hydrology intact is the most important thing. Currently, drainage is the most dangerous driver for tropical peatlands. Not only it stops the formation of peat by eliminating water as the main component in the mire formation, but also it is prerequisite for logging and agriculture activities. In addition, it makes the organic soil of peatland area vulnerable to wildfires. Drainage, along with deforestation and fires, is the main driver behind the rapid degradation of tropical peatlands since last two decades. Those all resulted in the change of hydrological conditions, typically groundwater level, and accelerate oxidative peat decomposition (Hirano, Kusin, Limin, & Osaki, 2015). These drivers are compounded by a complex mix of indirect socioeconomic, policy and climate change-related factors (Dohong et al., 2017).

One example of how devastating AWs to the tropical peatlands is MRP (Mega Rice Project). In the 1990s the Government of Indonesia decided to develop one million hectares of peatlands for agriculture in Central Kalimantan on the Island of Borneo by constructing thousands of kilometers of canals resulted in over-drainage (Ritzema, Limin, Kusin, Jauhiainen, & Wösten, 2014). In consequence, many wildfires occurred and caused irreversible damage to the overall peatland's ecosystem (Ishii et al., 2015)

How important tropical peatland forests to biodiversity can be seen from the explanation by (Harrison & Rieley, 2018). Collecting reports and results of other research they highlighted clearly the high biodiversity of the region's peat swamp forests and the consequent importance of their protection for biodiversity conservation. For instance, in a study in Kalimantan, it was reported the presence of more than 1,100 potential species (615 confirmed so far), including 46 that are globally threatened and 59 that are protected by law in Indonesia. While another study in Cambodia, a country in which peatlands and their biodiversity have received very scant research attention, the presence of 26 plant species were recorded.

The loss of biodiversity is something cannot be compensated in any method of drainage based agricultural activities in tropical peatlands. From 258,650 higher plants that have been recorded worldwide, 35,000-40,000 can be found in Indonesia (Rahajoe et al., 2015). However, there is much we still do not know about the biodiversity of these ecosystems, which is a hindrance to their effective conservation (Harrison & Rieley, 2018). One for sure is that land cover change of tropical peatlands almost certainly brings impact to its biodiversity.

Insular Southeast Asia experienced the highest level of deforestation among all humid tropical regions of the world during the 1990s. Due to the exceptionally high biodiversity in Southeast Asian forest ecosystems and the immense amount of carbon stored in forested peatlands, deforestation in this region has the potential to cause serious global consequences. (Miettinen et al., 2011).

Fire in peatlands is not something new for people in most part of Indonesia, in particular people in Kalimantan. They have used land fire for the benefit of their agriculture systems. Yet recently, wildfires (land and forest fires) becomes serious problems.

Fire is highly correlated with land cover changes. Most fires were detected in degraded forests. Ninety-eight percent of all forest fires were detected in the 5 km buffer zone, underlining that fire is the major driver for forest degradation and deforestation. (Langner et al., 2007). Recurrent fires are the principal direct drivers of peatland degradation, and that drivers are compounded by a complex mix of indirect socioeconomic, policy and climate change factors (Dohong, Aziz, & Dargusch, 2017). These on-going events not only endanger the existence of numerous forest species endemic to this region, but they further increase the elevated carbon emissions from deforested peatlands thereby directly contributing to the rising carbon dioxide concentration in the atmosphere (Miettinen et al., 2011).

Finally, one of the most crucial problems with tropical peatlands is related to the deforestation. Studies show that while the average deforestation rate such as in Kalimantan was 1.7% per year, the rate is higher in peatland area (2.2 % per year) (Langner, Miettinen, & Siegert, 2007; Miettinen, Shi, & Liew, 2011). The rate is including tropical peatlands in a protected forest. A study in Sumatera found that peatland will shrink 37% by 2040, including 25% in the protected forest (Elz, Tansey, Page, & Trivedi, 2015)

1.2.2 Challenges in RS and PAD analysis for integrative tropical peatland monitoring

There are two dimensions in the tropical peat deforestation monitoring. Physical monitoring is related to biophysical issues such as land cover changes, water table level, soil subsidence and its chemical properties, and carbon storage and release. These issues are much greater than the issue of deforestation in general. These issues can be separate matters in the deforestation issues as a general topic, but can only be seen as an integral part in the tropical peatland deforestation. Because these issues are linked to each other in the tropical peatland case.

RS is an increasingly used technique to monitor deforestation. For tropical peatland area, this technique is certainly not less important. Yet, to fully understand the problems, another dimension should also be included. That is the social aspect of the deforestation. In this case, human activities are the main factor behind the root of tropical peatland deforestation as mentioned in literature. Therefore, RS Images and PAD are very important data sources. However, challenges exist in both RS analysis and PAD analysis. As a tool for biophysical assessment, current RS techniques for monitoring artificial waterways (AW), human made structures such as canals and ditches, are less studied, particularly for traditionally built canals which usually very small in size. Pixel-based RS may not really appropriate to do so. A Geographic Object-Based Image Analysis (GEOBIA) is more appropriate. Meanwhile, for monitoring human factors of deforestation, PAD analysis requires appropriate base maps as a geocoding tool to spatially analyse the data.

1.3 Research Objectives

This research is aimed at developing an integrative method for monitoring tropical peatland deforestation in which biophysical aspects and human-socio factors are both assessed. Remote Sensing (RS) Images and Public Administrative Data (PAD) are used as data sources. However, challenges exist in both RS analysis and PAD analysis. As a tool for biophysical assessment, current RS techniques for monitoring artificial waterways (AW), human made structures such as canals and ditches, are less studied, particularly for traditionally built canals which usually very small in size. Pixel-based RS may not really appropriate to do so. A Geographic Object-Based Image Analysis (GEOBIA) is more appropriate. Meanwhile, for monitoring human factors of deforestation, PAD analysis requires appropriate base maps as a geocoding tool to spatially analyse the data. Therefore, this study develop a framework in which biophysical aspects and human factors are assessed simultaneously for a comprehensive tropical peatland monitoring. Land cover change and AW development are target of the assessment. They are indicators of human interference to the tropical peatland. For land cover changes, assessment is conducted using supervised classification with Landsat images as the main data source. Meanwhile, for AW detection, integration of local knowledge and image processing is applied in a GEOBIA approach of RS analysis. Further, in order to understand human factor behind the AW developement, the result of detection is integrated with PAD using RT (Rukun Tetangga/Neighborhood Association) as spatial key. For the purpose, RT Base Map (RTBM) is developed using village sketch maps of population census. However, typical sketch maps problems including distortion, schematization, and incompleteness add more challenges to the boundary uncertainty issue in the development of RTBM. To solve the issues, RT is plotted from the sketch map. In order to make it possible to play as a linker for geocoding though uncertain in the boundary, the RT is separated as point (landmark, centroid), line (rivers, roads), area (boundary) before georegistered as a new base map. Further, a data model is developed to build the RTBM before using it as a geodocing tool. After an accuracy assessment, it was found that the procedure can improve the base map accuracy from 49 percent as of direct digitization to be 75 percent. As a case study, this research scrutinized Sebubus Forest in West Kalimantan Province, Indonesia.

1.4 Originality and significance

This research keen to claim at least three original ideas in the work. First, this study use a new systematic understanding of the deforestation in the tropical peatland. The systematic understanding encompasses the biophysical aspects and human-socio aspects. The integration of the two aspects differentiate this study from previous ones. The latest study on peat monitoring such as of (Hirose et al., 2015) for example, despite giving a very comprehensive perspective on the tropical peatland monitoring system, is missing the key point on human socio aspects. Therefore, this study attempt to fill the gap and keen to claim that it is pioneering such kind of effort.

This study emphasizes the role of AW as the key factor in the tropical peatland deforestation process. Because, the human-made structures are the main condition for people to access the forest and transport the products from the forest. Therefore, the detection of AW and analysis of the human-social components behind the development of the structures is very important. In order to be able to scrutinize the human-social factor behind the development of AW in the tropical peatland, this study develop a method of AW detection in which integration of local knowledge and image processing is applied in a GEOBIA approach of RS analysis, and development of RTBM as a geocoding tool for analyzing PAD from local government's databases.

For monitoring human factors behind the deforestation, PAD analysis requires appropriate base maps. Current smallest available administrative base map (village level) in the Indonesia National Spatial Data Infrastructure (NSDI) may not adequate for spatial-based PAD analysis due to large size of villages in most of forest areas. Using the base map may mislead the analysis. RT is a smaller administrative units at neighborhood association level. The key challenge to develop such base map is due to uncertainty in the RT's boundary delineation because it is designed for population-based instead of spatial-based administration. That is why the base map yet exist. Even data source for developing such base map is very hard to find.

However, this study found a source of data. It is village sketch maps population census. The data is not perfect. Typical sketch maps problems including distortion, schematization, and incompleteness add more challenges to the boundary uncertainty issue in the development of RTBM. Yet, this study managed to develop a standard procedure to cope with the challenges. After an accuracy assessment, it was found that the procedure can improve the base map accuracy from 49 percent as of direct digitization to be 75 percent. As a case study, this research scrutinized Sebubus Forest in West Kalimantan Province, Indonesia.

Scientifically, this study contribute to the enrichment of literature on the tropical peatland monitoring. This study also enrich the literature on PAD domain which less discussed up to this study. Developed model also has several conceptual development for PAD analysis. The relationship between data and space is very important concept for future understanding about PAD. On the other hand, development of new base map, contributes on understanding the spatial uncertainty of administrative entities and how to cope with it. In the practical aspects, this research contribute to the improvement of Indonesia tropical peatland monitoring efforts. The detection and presentation of AW in the tropical peatland give a very clear picture on the distribution, states, and stages of human made structures. The detection and presentation lead to possibly stop any AW 's project from entering the forest. More over, the procedure of RTBM Development could be a model for developing a new layer of Indonesia NSDI. While, the data sources of this thesis is prevalent and accessible for local governments in Indonesia, it can be used to enhance policy recommendation for specific target of poor RT for effective and efficient social development policy.

2. LITERATURE REVIEW

2.1 A brief review of tropical peatland ecosystems.

2.1.1 Concepts of tropical peatland

For a deep discussion on peatland, it is important to first differentiate several terms and concepts that are related but often confusing. The terms and concepts such as Wetland, Peat, Peatland, Mire, Suob, and some others are often used interchangeably but in fact, has differences one to another.

IPCC in its guidelines (IPCC, 2013) divided soils into four categories; drained mineral soil, wet mineral soil, wet organic soil, and dried organic soil. The last two are what famously known as peat. M. Schumann & Joosten (2008) differentiated some of the terms as follows: a peatland is an area (with or without vegetation) with a naturally accumulated peat layer at the surface. Wetland is peatland mainly consists of wet organic soil and is inundated or saturated by water at a frequency and for a duration sufficient to support a prevalence of vegetation typically adapted for life in saturated soil condition. Mire is a peatland where peat is currently being formed. Since peat is normally formed under waterlogged conditions, Mire is wetland in nature. Therefore, peatland, where peat accumulation has stopped, is no longer a mire. Suob is wetland with or without a peat layer dominated by vegetation that may produce peat. Besides the terms explained by Schumann and Joosten above, there are also some other terms familiar with this topic. For example, Peatland with vegetation is often called as “Peatland Forest” or just simply “Peat Forest”. Meanwhile, if the wetland is covered by vegetation then it is usually called peat swamp forest.

Meanwhile, peat or organic soil has many technical definitions. For example, Hardjowigeno dan Abdullah (1987) defined peat as soil which is formed from organic materials (whether they have been decomposed or not). In Indonesian Minister of Agriculture Regulation, Number 14 the Year 2009, peat is described as soil which is resulted from the accumulated formation of more than 65% organic materials of natural decomposition of plants which once grew on it and experience a barrier to its total decomposition because of anaerobe and wet situation. Differently, (Schumann & Joosten, 2008) describes peat as sedentarily accumulated material consisting of at least 30% (dry mass) of dead organic material.

The definition of peat is still a hot topic in current academic and scientific discussions. Latest, a new definition of peat is proposed in which key elements of carbon contents or mineral content and minimum depth are considered for a comprehensive peatland definition (Osaki, Hirose, Segah, & Helmy, 2015). They suggested that peatland should be defined as an area with an accumulation of partly decomposed organic matter, with ash content equal to or less than 35 %, peat depth equal to or deeper than 50 cm, and organic carbon content (by weight) of at least 12 %. They also suggested four categories for peatland delineation with the classification namely: Peat Depth, Peat Layer, Hydrological area in peatland, and land use in peatland. This definition is the most comprehensive because all important aspects of the creation and sustainability of the peatland are included. For example, social aspects of the peatland are accommodated in land use. Meanwhile, the hydrological area contains not only the soil and vegetation where the peat exists but also its supporting systems such as water catchment and geographical shapes influence the whole ecosystems.

However, the most important thing for understanding peatlands is about the connection between plants, water and peat. The three components are very closely connected and mutually interdependent. The relationship between the components is well described by (Martin Schumann & Joosten, 2008) which explained that the plants determine what type of peat will be formed and what its hydraulic properties will be. The hydrology determines which plants will grow, whether peat will be stored and how decomposed the peat will be. The peat structure and the relief determine how the water will flow and fluctuate. These close interrelations imply that when any one of these components changes, it will certainly impact the others. The impact not necessarily at an instant but often inevitably in the long run.

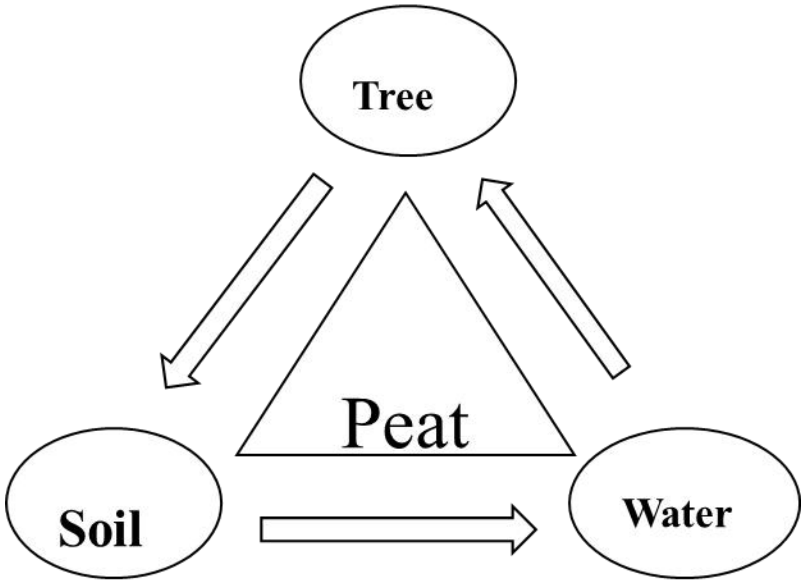

Figure 1: The cycle of peat generation

Sometimes it is quite confusing to differentiate some closely related terms connected to peatland or peat. Some terms like peat swamp forest, peatland, peat, mire, wetland, suob, etc may refer to the same object with slightly different distinction. Therefore, it is important to clarify first the term before we proceed with further discussion.

Amongst many descriptions, this of Schumann and Joosten (2008) are might hopefully very helpful. It is easily understood for the differentiation of those tricky terms. They differentiated those terms as follows:

1) Peatland is basically part of wetland ecosystem. In those wetlands where the remains of dead plants and mosses do not fully rot away, under conditions of almost permanent water saturation and consequent absence of oxygen they accumulate as *peat*.
2) A wetland in which peat is actively accumulating is called *mire*. In most mires, the process of peat accumulation continues for thousands of years so that eventually the area may be covered with meters thick layers of peat. An area of land with soil of peat is called a *peatland*.
3) Suob is wetland with or without a peat layer dominated by vegetation that may produce peat.
4) Peat is sedentarily accumulated material consisting of at least 30% (dry mass) of dead organic material. (Schumann & Joosten, 2008)
5) A peatland is an area (with or without vegetation) with a naturally accumulated peat layer at the surface. (Schumann & Joosten, 2008)
6) The other term is Peat swamp forest, which is described as waterlogged forest growing on a layer of dead leaves and plant material up to 20 meters thick.

In Indonesia, peatland ("Kawasan Gambut") is defined for two main purposes; theoretical or academic purposes, and authoritative or regulation purposes. In the theoretical/academic life peat at first is defined after Hardjowigeno dan Abdullah (1987)' "tanah yang terbentuk dari timbunan sisa-sisa tanaman yang telah mati, baik yang sudah lapuk maupun belum" (soil which is formed from organic materials whether it has been decomposed or not). This definition is often too simple practical purposes. A more detailed description can be depicted from the Indonesian Minister of Agriculture Regulation No 14 the Year 2009. According to the regulation, peat is described as soil which is resulted from the accumulated formation of more than 65% organic materials of natural decomposed plants which once grew on it and experience a barrier to its total decomposition because of anaerobic and wet situation. (Gambut adalah tanah hasil akumulasi timbunan bahan organik lebih besar dari 65% (enam puluh lima prosen) secara alami dari lapukan vegetasi yang tumbuh di atasnya yang terhambat proses dekomposisinya karena suasana anaerobic dan basah).

Another simple definition can also be found from other Indonesia Regulation: Government Regulation Number 71 the Year 2014 about Protection and Management of Peat-land Ecosystems, in which peat is defined as organic material formed naturally from imperfectly decomposed plantation remains, which is accumulated in the swamp. This regulation also defines Peatland Ecosystem, which it defines as a system of peat-land elements that form a comprehensive interdependence unity in their balanced stability and productivity. In addition, the same regulation also gives a definition of hydrological peat-land unity, which is defined as a peat-land ecosystem lying between two rivers, or between river and sea or swamp.

Peat-land can be divided into several types. Based on its complete systems, Peat-land can be divided into eight types (Davis and Anderson 2001); un-patterned fen in stream valley, un-patterned fen in open basin, un-patterned fen in closed basin, ribbed or string (patterned) fen, gently convex bog, eccentric bog, domed bog with concentric pattern, and plateau (coastal) bog. Each type has distinct shapes geographically.

On the other hand, based on its decomposition maturity, Peat-lands are classified as Fibric, Hemic, or Sapric. Fibric peats are the least decomposed and comprise intact fiber. Hemic peats are more decomposed, while sapric are the most decomposed. Another type is peaty soil, that is mineral soil with very shallow peat blanket.

Wahyunto et al (2004) tabulate range and mean of bulk density and also C Organic substance of peat as follows:

Table 1: the classification of peat

NO	Peat types	Bulk density (gram/cc)		C-Organic (%)	
		Range	Mean	Range	Mean
1	Fibric	0.11 – 0.19	0.13	40.02 – 49.69	42.63
2	Hemic	0.20 – 0.24	0.23	34.52 – 040.01	36.24
3	Sapric	0.25 – 0. 29	0.27	32.57 – 34.50	33.53
4	Peaty Soil	0.30 – 0.40	0.32	26.85 – 32.55	30.75

Note: peatland with peaty soil (less than 50 cm thick) is generally classified as mineral soil

Bulk density of Fibric peats ranged from 0.11 until 0.19 with its mean 0.13 per gram. Carbon Organic on its soil is around 40.02 % until 49.69% with its mean at 42.63 percent. Hemic peats, however, have more bulk density per gram (0.20 – 0.24), but less C-Organic percentage. Based on its mean, Hemic peats tend to have a higher bulk density from its ranged table (0.23). Anyhow, for its mean of C-Organic percentage tend to be a normal distribution. Sapric peats are also normally distributed. Bulk density of this peat type is around 0.25 until 0.27 gram/cc with its mean at 0.27. While its mean of C-Organic percentage is at 33.53 from ranged 32.57 until 34.50 percent.

Andriese (1998) classifies peatland classifications into six categories:

1. Topographical classification; based on Topography and morphology, peatland can be known as low moor, transitional moor and high moor

2. Classification based on surface vegetation; based on surface vegetation, peatland can be divided accordingly to main vegetation covers its surface
3. Classification based on botanical origin; based on this classification, peatland can be known as moss peats, saw-grass peats or woody peats
4. Classification based on physical characteristics; Hemic, fibric, and sapric as above mentioned are types of peatlands based on physical characteristics
5. Classification based on chemical properties; based on chemical properties peatland can be eutrophic, mesotrophic, or oligotrophic
6. Classification based on genetic processes; tropical peatlands and temperate peatlands is types of peatland based on genetic processes.

2.1.2 Distribution of peatland in Indonesia

Peatlands in general spread in around 3 percent of 4 million Km2 land surface of the earth. It is mainly located in the northern hemisphere including Russia, Canada and other European countries (Josten 2008, IPS 2008). Meanwhile, tropical peatlands can be found in South East Asia, mostly in Indonesia and Malaysia.

In Indonesia, peat-land is estimated covering 14.91 million hectares of the country's land area (Balitbang Pertanian, 2011). The unique ecosystem is mainly dispersed in coastal parts of Indonesia main Islands such as Sumatera, Kalimantan, and Papua. But can also be found partially in other islands such as Java, Sulawesi and many small islands. Sumatera Island has the largest peat-land areas in the country with total 6.44 million hectares. While Kalimantan Island of Indonesian part has 4.78 million hectares and Papua with 3.7 million hectares.

In Sumatera, peatlands mainly cover a huge area of East Coast from Jambi until North Sumatera. In Kalimantan, Peatlands are dominating Western Coast, span from

West Kalimantan until Central Kalimantan. While in Papua they are mainly cover the Western coast of the Island.

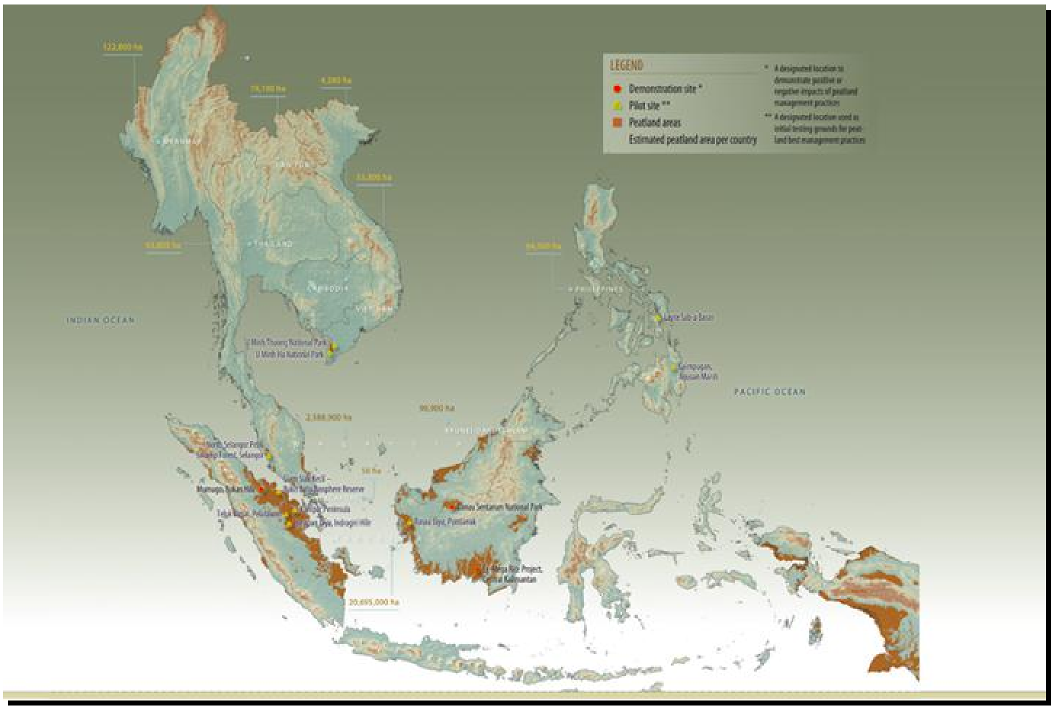

Figure 2: peatland distribution in Indonesia (courtesy of Ministry of Forestry of Indonesia)

2.1.3 Tropical peatlands and environmental problems

Some issues related to Peat-lands have attracted scientists and policymakers' attention from local to global communities. In general, there are six main issues related to peat-lands. The first is about peat-lands conservation and preservation. The second is about peat-lands utilization. The third is about peat-lands properties and development and the fourth is about disaster related to peatlands. While the fifth is about peatland and communities, and the last is about peatland detection and mapping.

Related to conservation and preservation, peatland is commonly discussed on its richness of biodiversity and its importance to ecology and environment (Michael Williams.1991). The fact that this type of land has a very important role for the whole earth ecological system is the main emphasis of the discussions. Its hydrological importance, biodiversity richness, and world carbon preserved in its soil make peatlands become subject of researches and policies. On the other hand, its huge existence is endangered in parallel to increasing demand for land use.

With its huge existence whole over the world, peatlands unavoidably importance for economic and social development (Rodney, James Giblett. 1996). Utilization of peat-lands for cultivation and other purposes however always result in adverse consequences. Peat-lands with its unique characteristics are hardly utilized for cultivation but for a few types of plantation. On the other hand, the utilization requires very careful handling for avoiding the environmental cost (Parish f., Lim, s. s., Perumal, b. and Giesen, w. (eds) 2012).

Irresponsible peatlands utilization and management in recent years has caused some peat-lands related disaster (Rieley, J. 2013, UNDP. 2006). Flood during rainy seasons and wild forest fires during dry seasons are amongst disaster commonly happened in tropical peatlands (Bizard, V. 2011). However, the most serious and globally attention disaster related to peat-lands are about climate change. As above mentioned, peatlands preserve around 550 GT carbon which once released to the atmosphere will significantly contribute to greenhouse gas emission (Page, S. E., Siegert, F., Rieley, J. O., Boehm, H.-D. V, Jaya, A., & Limin, S. 2002).

The other focus of discussions related to peatlands is related to its attributes. Its hydrological systems, characteristics, process of development, and its distribution are amongst attributes that much researched (Adriesse 1988). Meanwhile, community-based peatland management is another point of attention. It includes aspects aforementioned. How communities can participate in the peatlands conservation and preservation is one example. While community' roles in disaster prevention and mitigation are also frequently discussed (, Page, S. E., Siegert, F., Rieley, J. O., Boehm, H.-D. V, Jaya, A., & Limin, S. 2002)

2.2 RS and tropical peatland monitoring

RS has become one of the increasingly applied techniques in natural conservation including in the tropical peatland research. RS techniques give several advantages for tropical peatland monitoring compared to the traditional approaches. The advantages are in terms of cost, spatial coverage and accessibility to remote locations. With increasing advancement on sensor's technology, RS can also give advantage to data accuracy. Using RS techniques, tropical peatland monitoring becomes easier for large scale peatland ecosystem.

In principle, peatland monitoring can be conducted in three levels of altitude: from ground level, airborne level, and spaceborne level (Hirose et al., 2015). Airborne and spaceborne are RS domain, while the ground monitoring can be done by survey, field observation, or census.

At airborne level, the current development of Unmanned Aerial Vehicle (UAV) becomes the leading technology for tropical peatland monitoring. Meanwhile, at spaceborne level, satellites usually equipped with two types of sensor capabilities: optical sensors and radar. Both sensors are widely used in tropical peatland research.

In the monitoring system, there are eight elements of tropical peatland that become the object (Hirose et al., 2015):

1. CO2 flux and concentration
2. Hotspots detection
3. Forest degradation and species mapping

4. Deforestation, forest biomass changes
5. Water level and soil moisture
6. Peat dome detection and peat thickness
7. Peat subsidence
8. And water-soluble organic carbon.

Current literature on the using of RS to monitor the above elements are abundant. However, those elements are merely focused on biophysical aspects. Meanwhile, using RS to monitor social aspects of tropical peatland deforestation may not appropriate. At least at the current stage, it is yet able to extract social data using the technology. Therefore, to comprehensively monitoring tropical peatland both in biophysical aspects and human-social aspects, another type of data source is required.

2.3 PAD as a source of spatial data

Despite the most common terminology to refer to data produced by public sectors is "administrative data", in this study we prefer to use PAD. Because, as administration systems can be divided into public administration systems and business or private administration systems (Ashirvatham & Asirvatham, 1994), the data generated by these two environments should also be (even though not necessarily always) differentiated.

As products of administration systems, the characters of the data absolutely resemble the systems in which they are produced. Because within two administration systems, each system has special values and techniques of their own which give to each its distinctive characters (Marume, Jubenkanda, & Namusi, 2016), the data produced in the system should also distinctive. As far as data in the concern, there are purposes of why they are generated, also how they are collected. For example, because public administration system is service oriented meanwhile business administration system is profit oriented in nature, therefore goods are naturally valued differentially in the two environments. That is why the government usually uses standardized price and private organization usually uses market price in their accounting. Furthermore, because government is service oriented, criteria for measuring, calculating, valuing, and presenting things are also different from private sector that is profit oriented. In fact, even between different government institutions, data can be differently presented due to the difference in formulating criteria and methodologies. For example, population densities presented by statistics offices usually differ from those of registry office. Population in statistics office usually counted by survey or census while in registry office it is by register.

While current general view regarding PAD is limited to quantitative/statistic records, the horizon of administrative systems, in fact, is far greater. In public administrative systems, qualitative records are rich and should not be excluded as valuable properties. Wallgren & Wallgren, (2014) mentioned three types of (Public) administrative data. First, some data are actually statistical data, those are statistics produced by authority for their own purposes. Second, are kinds of variables which are legally important, if you provide the wrong information for these, you have done something illegal and can be punished. Examples of this kind of data are including income assessments and tax returns. The third is a category of variables represents decisions made by an authority.

While such data are not designed for research purposes, they often have significant research value, especially when linked to other datasets or to user-generated surveys (Elias, 2014). In terms of statistical records, for example, PAD usually consists of large repositories. For instance, healthcare administrative databases are large repositories of data on healthcare systems that are routinely collected by health care providers and other institutions (Herbst, 2013). Moreover, compared to economic censuses and business surveys, administrative data are less burdensome to collect and produce more timely, detailed, and accurate data with better coverage (Rivas & Crowley, 2018). They also have fewer problems with attrition, non-response, and measurement error than traditional survey data sources (Card, Chetty, Feldstein, & Saez, 2010). However, because the origin is not for research, PAD may not instantly usable for research and analysis. In some extent, they are more problematic than traditional research data.

The most common issues related to PAD are their quality, particularly related to methodological/intrinsic consistency, accessibility, completeness, and ethical/privacy-related matters (Connelly et al., 2016; Herbst, 2013; Mazzali et al., 2016). Methodological consistency issues usually happened to longitudinal PAD. In Indonesia for instance, criteria for defining poor families have been changed several times, likely influenced by political interest. On the other hand, accessibility is also problematic for many researchers. Despite its abundance availability, accessing PAD is not always easy. In many cases, information transparency is not always guaranteed even in a very democratic country. Often accessing PAD requires complicated bureaucracy. Completeness is another problem. Some of records or data are produced not by single producers but by several horizontal institutions. Once a single unit does not produce similar records, the completeness of overall records is in a problem. Meanwhile, ethical/privacy-related matters are also an important aspect of PAD. Records or data linking to personal or confidential data requires deliberate consideration before using them. Deidentification can help to solve this matter but an appropriate framework and legal foundation is required

Relationship between human-social activities with places or geography is as clear as the reciprocal relationship between human and the environment. Considering that every human activity always certainly occurs only in a specific spatiotemporal dimension, thus every human activity will always be connected to specific spatiotemporal elements. The connection between the human socio-economic, politic and cultural activities with spatial elements is therefore unavoidable. Yet, not all of the connection or relationship has been well explained. Either because of lack of frameworks to understand it or just because of limited available data to analyze it. In this sense, PAD as a depiction of human sociopolitical activities is one very potential resource for extracting human-environment relationships. Therefore, linking PAD using geographical elements as the platform can be one good opportunity for various types of res

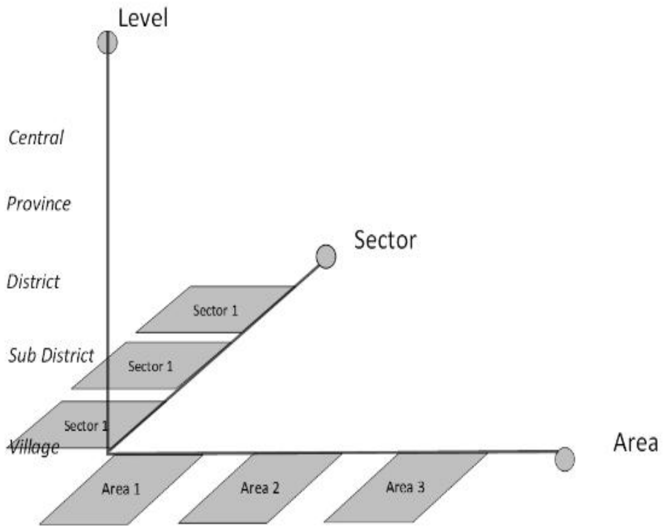

Figure 3: three-dimensional perspective of the relationship of PAD and place

PAD gives information about what has happened or what will happen in geographical space. For example, a database maintained by agriculture department usually records yielded crops produced from a specific field or village. The same institution may also record cultivated area, irrigated area, or even deforested area. While the registry office's database usually gives us information about a number of people or households populate an area. Public work office usually has records regarding roads, buildings, and other constructions that exist in a specific area.

Directly, PAD tells stories on how landscapes have been occupied and altered. PAD also give an image of landscapes. Indirectly they can give further information about the state of the geo-environment. For instance, yielded crop may give information about chemical substance in soil (Clostre, Letourmy, & Lesueur-jannoyer, 2017), as population density or energy consumption can give clue on air and water pollution (Khan et al., 2016; Kumar & Saroj, 2014; Reder, Alcamo, & Flörke, 2017). Administrative database of the health department or hospitals probably depicts the degree of air pollution (Koplitz et al., 2016; Lobdell, Jagai, Rappazzo, & Messer, 2011) or even chemicals substance in water or soil (Beale, Hodgson, Abellan, LeFevre, & Jarup, 2010).

PAD probably can also give us information about the geoenvironmental change. For example changes in forest covered area can be linked to population density (Ehrhardt-Martinez, 1998; Tritsch & Le Tourneau, 2016). Another study also showed that income and energy consumption has a significant relationship to CO2 emission (Alam, Murad, Noman, & Ozturk, 2016). Changes of the aquatic environment or river geomorphology to some extent can be detected from sedimentary generated by human population (L. Gao et al., 2017). PAD may also be used to examine the loss of biodiversity such as bee colony (Moritz & Erler, 2016). In short, the PAD can give us information about various relationships between human and the geoenvironment.

In Indonesia, data aggregation and their relationship to geographical area can be understood as a three-dimensional relationship (see Figure 3). Government or public institutions' hierarchy downs from central to local governments. In some extent, they can reach the lowest level that is village level. Meanwhile, at each of the level, sectors govern their jurisdiction in a determined area. If temporal dimension is added, the relationship will be four-dimensional. On the other hand, there is also an institution which specifically copes with data beyond jurisdiction or sectors. Statistic office is an example.

Indonesia Statistics is one of public institutions producing various types of statistical records or data in the country. The institution has a structure vertically stretched from central level to sub-district level but also often has representatives working at village level. The institution produces various types of data for national interest, but also often cooperates with local governments to produce data for local needs.

Beside Indonesia Statistics, all public agencies or institutions in general, are producers of PAD. They produce various types of database depending on their jurisdictions. For example, registry offices produce population database; education departments generate pupil and school databases; and so on. Usually, the databases are aggregated according to organizational structures and their administrative area. Because some institutions are vertically structured into administrative levels and horizontally divided into several administrative units, mostly records or data can be aggregated based on those administration machinery.

Often two or more producers produce typically similar databases. For example, the registry office produces data of population by administrative units which usually published every year. Meanwhile, Indonesia Statistics usually also publish data of population by administrative units every year. Despite typically have the same name and object, the figures showed by both institutions mostly different. This can happen because each institution uses a different method due to the difference in service delivery purposes. This can be confusing for some users.

If we look on the above review as well as other theoretical development, there are at least three conditions prerequisite to the usability of PAD for spatial based research and analysis.

1. First, in order to aggregate information vertically for higher level management and policy functions or to share data horizontally among diverse operational functions, appropriate geocoding capabilities must be available (Huxhold, 1991 p.147). Geocoding capabilities are including the existence of geolocation. This can be meant the existence of accurate point refers to an exact location on earth, but also the extent of an area or structures such as roads, rivers or boundaries. The most common used geolocation is geographical objects such as administrative areas, buildings, land parcels, etc. Without geolocation identifier the data cannot be associated with specific location thus becomes impossible to link them geographically. If the data are aggregated by administrative area as shown in Fig. 2 below, then the administrative area is the geolocation identifier.
2. Second, an appropriate base map must be available. A base map is used as a platform for analyzing the data spatially. For instance, to visualize data geographically, a map is required to see how the data distribute spatially. A base map is required for visualization of geolocation identifiers into geographical plane.
3. Third, the data or records and the base maps should have the same geo-reference both in term of spatial and temporal. A base map, particularly for administrative

boundary base map, often changes following political or administrative process. How the data refer to a boundary should be in line with the base map. Otherwise, the analysis will result in bias or un-executable. For example, a data mentions an administrative boundary named A. The base map may also refer to the boundary A but can be for the condition of five years before. If we link the data and the base map, it will cause a problem if the administrative area of boundary A has dramatically changed since the base map's temporal reference.

2.4 Administrative boundary base maps in the NSDI

In the ISDI, there are eight types of base maps supporting the components of geospatial data. The base maps are coastal line base map, hypsography base map, hydrography base map, toponym base map, administrative boundary base map, transportation and utility base map, building and public facility base map, and landcover base map. All of the base maps are part of the basic framework which is important for developing, maintaining, managing, and sharing thematic geospatial information.

Based on Indonesia Geospatial Act (Law number 4 the year 2011), base maps are standardized into ten scales vary from 1:1.000.000 until 1:1.000 (see Figure 4). However, for the administrative boundary base maps, it should follow the administrative systems. Currently, the Indonesia administrative system has five levels of government structure. The central government is the highest or the first level. The rest four are sub-government structure. Provinces or special areas are the second level sub-government. Regencies and municipalities are the third levels. Sub-districts are the fourth, and the last is villages or any names based on local wisdom. Map's scale for each of those administrative level depends on local characteristics. For example, villages in Jakarta, Banten, West Java, Middle Java, Yogyakarta, Ease Java, and Bali averagely have an administrative area between 1 to 5 km2 each. While, in Kalimantan and Papua the average size can be 100 to 250 km2. Therefore, in term of scale, administrative boundary base map vary depend on the location.

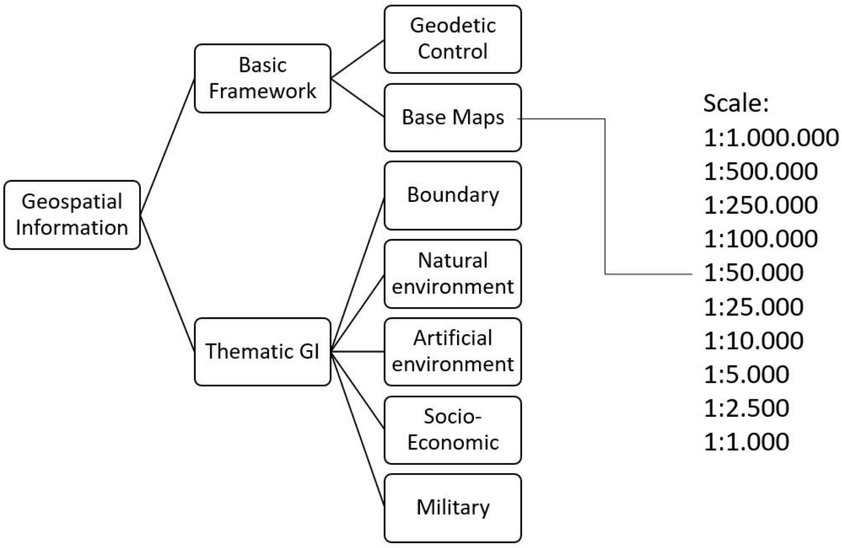

Figure 4: Base maps, scales, and structure of geospatial information in ISDI

Currently, in the ISDI geoportal, administrative boundary digital base maps are available only until level 4 of the administrative systems. However, some local government may have their own digital base maps that reach level 5 (village level).

Besides the five levels of sub-government, in fact, there are also some community level administrative systems. In the Guideline Book for Village Mappers published by (BPS, 2009), administrative units smaller then village is called Sistem Lingkungan Setempat (SLS), which literally can be translated as Local Neighborhood System. RT is one of SLS with an administrative area. It is the smallest administrative unit in Indonesia. Name of this administrative unit is not always RT. In some local governments, the name can be different. However, RT is general name and the most widely known.

RT is an administrative unit firstly introduced by the Japanese administration in Indonesia on January 8th, 1944 (Kartodirdjo, 1987). RT in Japanese is called Tonarigumi (隣組). At its early establishment, an RT was designed to consist around 20 households but later developed based on local policy and circumstances. For example, government of Malang Regency in East Java enacted a regulation determine the size of an RT should be consist of 30 to 50 households.

RT as administrative entities exists until today in the Indonesia administration system. Latest, it is regulated in the Indonesian Home Affair's Regulation (MOHA, 2007). The purpose of this administrative entity is to support village administration organizing its people. The territory of an RT is determined by the community's agreement. Since the prime concern is the population, the area of the territory often blurs, known only by the inhabitant of the RT or correspond villagers. That is the reason why mapping the administrative unit requires a deep survey and very costly.

Every single RT in a village has a unique identity, which is usually identified by numbers. It has an organizational structure headed by a chief. The main function is to help the village's chief in administering the area and its member households. In regards to its administrative area, RT is commonly used for identifying an address in administrative affairs. Roads and house's number are occasionally found. However, in many official documents, address usually identified by name of RT. Therefore, it is a potential geocoding tool. Unfortunately, it has not been given much attention in the ISDI.

ISDI has been developed as a key point in the country's One Map Policy (OMP). Improving data quality, reducing costs, and reducing the duplication of efforts among government's institutions are the goals of the introduction of ISDI. The framework of the ISDI is formalized in the Geospatial Information Act enacted in Law Number 4 the Year 2011. The framework is adopted from the FGDC's (Federal Geographic Data Committee). It has two aspects: Data, Procedures and technology for building and using the data, and institutional relationships and business practices that support the environment.

Related to data, procedures, and technology, ISDI adopts a network system provided by Japan's NTT Data and ESRI's ArcGIS Server as a foundational technology. A geoportal named InaGeoportal has been established as a platform for data sharing. Seven thematic base maps are decided as the core of data sharing. Those are administrative boundary base maps, forestry base maps, spatial planning base maps, infrastructure base maps, land and service base maps, natural resources and geoenvironmental base maps, and special zone and transmigration base maps. The base maps cover all the country's area which is divided into 34 provinces. The scales vary from 1:1.000.000 (national level) until 1:10.000 (village scale). On the other hand, nineteen institutions are supporting the environment.

Through the Geospatial Information Act, the Indonesian government is also aiming at distributing access to authoritative data for local governments, private sectors, and the public. They are also the main data producers in the system. *The s*uccess of the NSDI relies on how the stakeholders including provinces and local governments, as well as the private sector, all working together (Environmental Systems Research Institute (ESRI), 2012). However, it is the implementation by the institutions and data producers which is a lack in the ISDI. Although SDI has been implemented successfully for some times at national level, the successfulness of implementation at local government level was varied (Sutanta, Aditya, Santosa, & Laksono, 2014). Even since Law No. 4 of 2011 on Geospatial Information was established, the implementation of the NSDI among institutions and local governments has still not been effective yet, which can be seen from the number of participants in InaGeoportal (Sahroni, Saleh, & Wijanarto, 2017).

3. FRAMEWORK AND METHODS FOR MONITORING DEFORESTATION OF TROPICAL PEATLAND

3.1 Research framework

Understanding key factors in the human tropical peatland relationship problems is central tenet in this study. Literature review and ground observations concluded that water table decrease and landcover change whether caused by logging (legal and illegal) or agricultural and forest industry activities inside and surrounding the forest are the main human interference contributed to the tropical peatland degradation.

Monitoring the deforestation of peatland, therefore, can be done through two approaches; physical change of the forest and human activities as the root of the physical changes. Meanwhile, physical changes can be detected by current developing RS techniques, human activities as the root of the changes cannot simply be detected by the technologies. Another approach is needed. In this case, analyzing PAD as a depiction of human social activities is proposed.

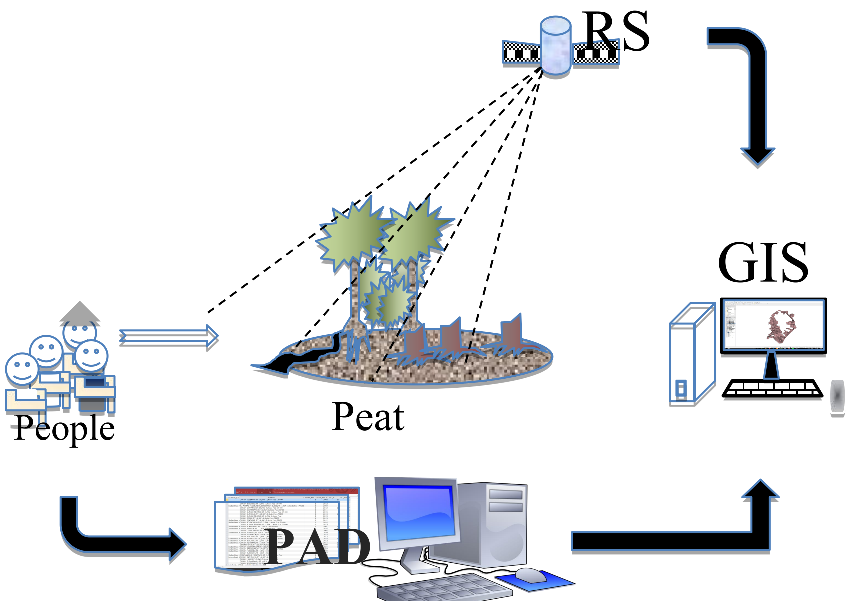

Figure 5: the logical framework of this study

3.2 Framework for monitoring deforestation of the tropical peatland.

As aforementioned, two crucial elements in the monitoring of tropical peatland deforestation are the existence of AWs and land cover changes. The existence of AWs means the disturbance of hydrology system of the peatland complex which influences the whole cycle of peat generation. Unfortunately, none of common agricultural activity in the tropical peatland can be done without AWs construction. In fact, the current problem with tropical peatland management is that it is based on the assumption that sustainable agriculture on peat can be achieved with a certain way of irrigation system. However, the current scientific view tends to support that business-as-usual management is not sustainable for tropical peatland agriculture (Wijedasa et al., 2017). A relationship with groundwater table depth shows that subsidence and carbon loss are still considerable even at the highest water levels theoretically possible in plantations (Hooijer et al., 2012). Therefore, conserving peatland on a landscape scale, with their hydrology intact, is of international conservation importance to preserve their distinctive biodiversity and ecosystems services and maintain their resilience to further environmental change (Roucoux et al., 2017).

Meanwhile, changes in land cover on the peatland for certainly also influence the peat generation. Because the peat layer forms from decomposed trees. It also impacts the richness of biodiversity. Of the 27.1 Million hectares (MHA) of peatland in Southeast Asia, 12.9 Mha had been deforested and mostly drained by 2006 (Hooijer et al., 2010). Conversion of tropical peatlands to agriculture leads to a release of carbon from previously stable, long-term storage, resulting in land subsidence that can be a surrogate measure of CO_2 emissions to the atmosphere (Hooijer et al., 2012). Therefore, preserving tropical peatland with their forest cover is important.

On the other hand, the importance of human-socio factors in tropical peatland is undeniable. Even it can be concluded that successful restoration of degraded peatlands must be relevant to socio-economic circumstances, and should not proceed without the consent and co-operation of local communities (S. Page et al., 2009).

AWs, landcover changes, and human social activities are of the concern in the proposed framework. AWs and landcover changes are the objects of RS analysis. There are two approaches to RS techniques are used. Pixel-based analysis is used for landcover changes monitoring. Meanwhile, GEOBIA is used for detecting and monitoring the existence of AWs.

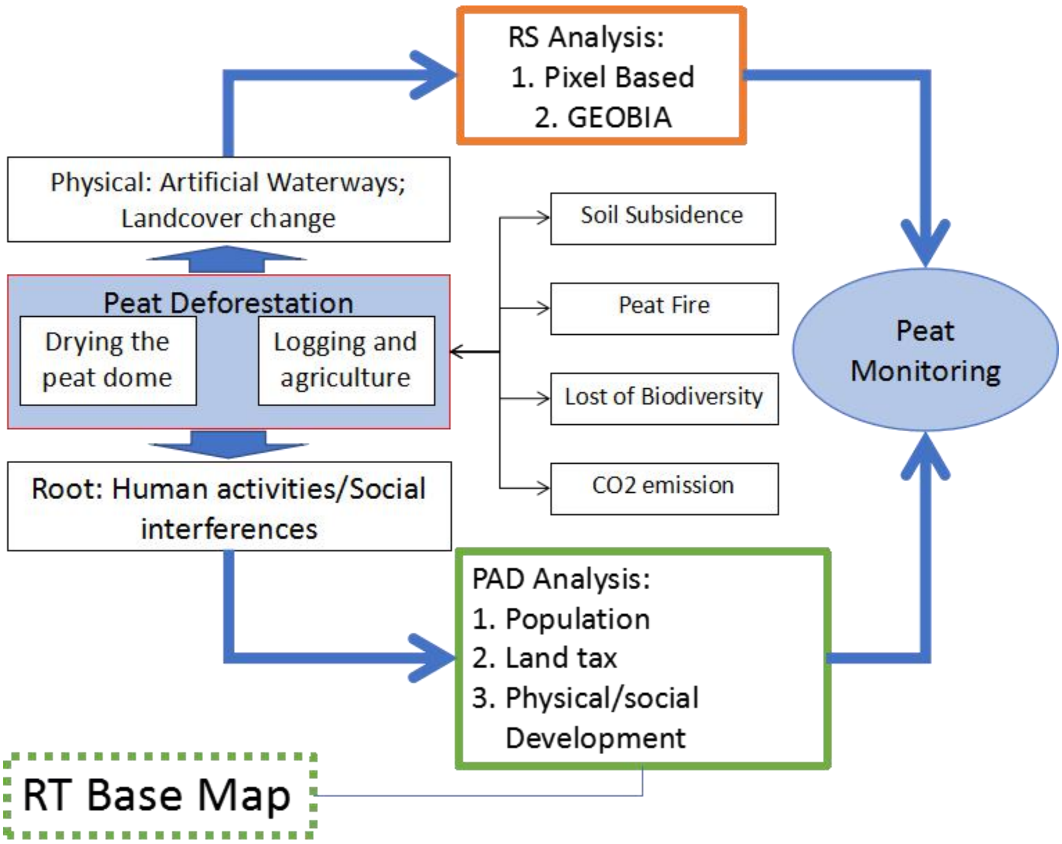

Figure 6: the proposed framework of this study

Human social activities are the root of the deforestation. Monitoring this aspect hypothesized in this study can be conducted through PAD analysis. Several public databases can be used as a source of data for PAD analysis. Some of them but not limited to this example; population registry, land tax registry, development project databases, etc. Details of that analysis are following on the next chapters

3.3 RS method for detection of land cover changes.

For land cover changes detection, Landsat Images archive can be downloaded from USGS website. Other sources of data can also be found. Some of popular source of data is: SPOT, ASTER, AVNIR-2 for medium resolution images. For high-resolution images can be obtained from RapidEye, Ikonos, and Quickbird. Meanwhile, for hyperspectral images can be obtained from Hyperion or HISUI.

There are two important stages in the analysis; image selection and data processing.

I. Image Selection

Image selection is important to ensure that analyzed image fit with the monitoring purposes. Because often required image cannot be found or not comply with research needs. Therefore, the selection of images for further analysis should be based on criteria as follows:

a. Analyzability of the image.

For example, if the research site is an area around 15.000 ha, which means around 10 percent of the total area covered by any single Landsat scene for path. This means that there are many possibilities regarding the analyzability of any single scene obtained. Therefore, visual selection is chosen to find analyzable images because that way is easier to find an image with good clarity; that is images either free of cloud on the area of interest or free from any other disturbance.

b. Possibility of image Informativeness.

Based on the context of interest, downloaded images may contain identical information one after another. Therefore, processing all analyzable images may not really efficient. Since the interest is about dramatic changes in landcover in the peat forest, only images that visibly show dramatic changes are further analyzed.

c. Interval of time

In the monitoring of landcover changes, it is often an interval of time is required. For example, scenes are aimed by an interval of five years starting in 1995. However, in case analyzable image collected for a specific year may not available, it can be slide forward or backward depending on availability.

II. Data processing

Selected images are processed using an application such as ERDAS Imagine, ArcGIS, or QGIS There are many other applications with image processing capabilities. Atmospheric correction can be done using ERDAS Imagine as well. Atmospheric correction is important for removing the influence of aerosols that primarily affect reflectance values in the shortwave length region of the electromagnetic spectrum (Y. Gao et al., 2015). Supervised classification is required to classify the land cover.

Land cover is classified into four categories; Water/cloud, Bare Land/Agricultural Land, Shrub/Agricultural Land, and Forest. Water or cloud is defining the existence of streams or waterlog in the peat soil. As it is well-known peatlands are originally waterlogged all year long (Agus, Mulyani, Nurida, Ariani, & Widiastuti, 2017). However, it is common that some area on peatland may water logged only during a particular time. Bare land is cleared land which often occurs when people begin their early stage of the agricultural process in peat soils. It also can be happened after severe wildfire. The shrub is a land area in which small trees start growing (woody plants usually less than 6 meters tall). Peatland usually quickly covered by shrub after land cleared. Mostly within one year, abandoned peatland will begin to be covered by shrub. Meanwhile, forest here is a group of big trees (more than 6 meters tall). Trees on peatlands mostly grow rapidly with high density. In some extent, trees in peatland can grow up reaching 180 meters tall.

3.4 RS method for detection of AWs development.

GEOBIA is currently developing techniques in RS. It is increasingly used following rapid advancement in satellite data resolution. This technique is getting attention because, with the high-resolution imagery, pixel-based analysis is not appropriate to understand the geographical object. In RS or image analysis, it is known that as long as pixel sizes remained typically coarser than, or at the best, similar in size to the objects of interest, emphasis was placed on per-pixel analysis or even sub-pixel analysis for this conversion, but with increasing spatial resolutions alternative paths have been followed, aimed at deriving objects that are made up of several pixels (Blaschke, 2015).

However, GEOBIA currently lacks a systematic method to formalize the domain knowledge required for image object identification (Rajbhandari, Aryal, Osborn, Musk, & Lucieer, 2017). This research proposes a simplified GEOBIA (GEOBIA) capitalizing GEHRI to monitor the development of AWs in a preserved tropical peat forest. A workflow consists of three sequential stages is conducted. It is a simplification of various complex object-based analyses. In the workflow, firstly the ground characteristics of AWs are summarized based on ground observations and local knowledge. In the second stage, object-based semantics were predicted using the summarized characteristics. In the last stage, the data were transferred and analyzed using a GIS application. To test the workflow, a case study was conducted in Sebubus Forest of West Kalimantan Province, Indonesia.

Alejandro Jaimes and Shih-Fu Chang (Jaimes & Chang, 2002) distinguished between the visual and non-visual content of an image. This distinction still becomes a key foundation in current Object-Based Image Analysis (OBIA). The visual content of an image corresponds to what is directly perceived when the image is observed (the lines, shapes, colors, objects, and so on). The non-visual content corresponds to the information that is closely related to the image, but that is not present in the image.

What knowledge or information required for an OBIA according to them, can be understood from a ten-levels of visual structure. The structure depicts a relationship between Syntax (percept), Semantics (visual concept), and Knowledge. The key to this structure is, the required knowledge corresponds to each level of the structure. Current development of GEOBIA, in general, can be traced back to this structure.

In short, bringing this concept into a simple applicable technique, we propose three stages of processes, which are applied in this study. The stages for monitoring AWs in tropical peat forest are aimed at helping to capitalize current familiar technology for involving the community's participation in managing the valuable ecosystem. The stages are:

1. The first stage is the collection of required information related to the AW's general characteristics at ground level. At this stage, fieldworks and ground surveys were conducted. Some interviews with key

informants consisting of local people and local government's officials are included at this stage. Some information such as general sizes and dimensions used as well as methods used by local people in constructing AWs are summarized. That information supposed to be the image of local knowledge on the subject. As aforementioned, the knowledge is required as semantics for detecting AW. It is also a valuable reference to differentiate AW from Natural Waterway (NW) or any other artificial structures that may characteristically have similarity with AW. For example, roads and electricity cable networks are structures that possibly have similar visual semantics on images.

2. After understanding the characteristics of the AW on the ground, the next stage is aimed at understanding the characteristics of the objects at the image level. Image analysis was carried out before on-screen visual digitization was conducted directly through the Google Earth Pro application. This software can be downloaded and installed freely. Fortunately, this application enables us to do on-screen digitization. This is very helpful for the digitization of investigated objects into geo-database.

   Digitization using GE produces files in KML (Keyhole Markup Language) format. It is a geographic information system format containing features such as images, lines, polygons, placemarks, 3D models, textual descriptions, etc. Those features are important for representing AW's properties under investigation. For simplification, in this case, lines are used to represent AWs.

The other important thing in the process is to grid the area. The grid is important to solve scale bias during context finding. To find the context of an object we have to scroll zoom in and zoom out to see the object from different scales. The gridding can be easily made in a GIS application and then opened in GE.

On the other hand, there are four AW's properties that determine their capability to transport water. The properties are the length, width, depth, and slope. However, the length of AW is the main focus of this research. The length of an AW shows the network of the structure and its influence to draining an area. Therefore, in this study AWs are digitized as lines instead of polygons. However, if it is required, the depth and width of AWs can be added later into the file's attribute, which is available in any GIS application, for further comprehensive analysis.

3. On the last stage, GIS application is used to analyze obtained geodatabase. While a simple analysis such as measurement of a feature can also be done directly in GE application, a transfer into specific GIS application is needed for better analysis and further processes. GIS is a computerized system for the capture, storage, querying, analysis, and display of spatial data, and is used predominately by the government, private companies, and nongovernmental organizations (NGOs) across Indonesia (Bretz, 2017). Common file format for GIS analysis is Esri Shapefile (SHP). Using GIS application, various data manipulation, enhancement, and linkage can be done. It is also useful for conducting further social and behavioral analysis. The use of GIS in social and behavioral sciences is an increasingly essential component as a tool for

acquiring and communicating geographic knowledge (Van Kreveld, 2017).

One of GIS application, which can be used for GIS analysis, is Quantum Geographic Information Systems (QGIS). It is an open source application that means any parties can simply download it from the Internet for full access to the application features. This application has several tools for GIS analysis.

There are various types of analysis can be done once the data have been transferred into a GIS application. However, in this paper, we give only two processes. The first is a mapping or visualization of spatial data. Mapping is important for analyzing a geographical position, distribution, direction, and extent of objects. Therefore, mapping or spatial data visualization is made to give a comprehensive picture of the AW development in the site. In this study, digitized AWs data are transferred from KML format into SHP format.

The second analysis is statistical analysis that is required to give a deeper understanding of the development of AW in the site. For example, to understand the spatial and temporal development of AW, a statistical summary is required. Questions such as, how long the AW has been developing over time? How many new AW systems exist in the area in a specific time? All can be answered using statistical tools. In the QGIS application, this aim can be easily achieved since the application has been equipped with some simple statistical tools.

Figure 7: 1 km gridded block to help the process of visual on-screen digitization

3.5 A method for developing RTBM.

Data for the development of a digital metric RTBM are village sketch maps of population census. The sketch maps were generated by Statistics Offices prior to decennial events of population census.

3.5.1 The village sketch maps of population census as a data source

Developing a metric base map of RT is a challenging task considering legal uncertainty with the delineation of the boundaries on the field. However, there is an alternative source of data. Village sketch maps of population census are expected to contain such valuable information for developing the base map.

Village sketch maps in principle can be obtained from local Statistic offices which conducted population census. The sketch maps are usually generated nation-wide in line with the scale of population census. It means the data should be available for whole villages in the country. However, In Indonesia, the sketch maps were used as back-office data and therefore had never been published. They were used as a supporting tool in the survey of population census. The maps usually can be obtained in scanned image format. The population census is a decennial agenda in Indonesia.

Guidelines were published prior to the census imposed to all statistic offices in the country. Mappers were trained and ensured to follow the guidelines in the mapping process. Based on this, it can be assumed that the data are uniformed, in which all scenarios of possible differences in the vast country are well accommodated. Therefore, one case study should be enough to make a generalization for the whole country.

Based on the guidelines, there are three scenarios in developing village sketch maps: first, a sketch map developed from satellite image with a coordinate system; second, sketch maps developed from a map with a coordinate system; and third, a sketch map developed from statistic sketch maps without coordinate system (BPS, 2009). Despite having slight differences, in general, there are three components in the village sketch maps: the header and footer, sidebar, and the main map. All the components are important for the digitizing process.

On the header, there is information about the identity of the sketch map. The name of the village is revealed. Also, the identity code for the village and the sketch map. This information is helpful particularly for locating the sketch in the georeferencing process in which the sketch maps must be brought into the correct corresponding village in the existing administrative base maps. On the footer, validation sign can be seen. The information is required to ensure that the sketch map has been verified by the authorized officer which means the sketch map process has followed the guidelines.

On the sidebar, there are information sections including administrative structure section, scale and legend section, statistic section, and validation section. All sections give valuable information to understand the sketch map. In the statistic section, for example, there is information regarding existing features in the main map. While in the validation section, information about the mapper is revealed.

On the main contents, the shape of the feature is drawn. There is information about coordinates, names of geographic features, and various administrative boundaries and landmarks. The main part of the sketch map is the main target in the digitization. Three elements in the main map are very important besides coordinate points. Topology names, boundary lines, and existing landmarks.

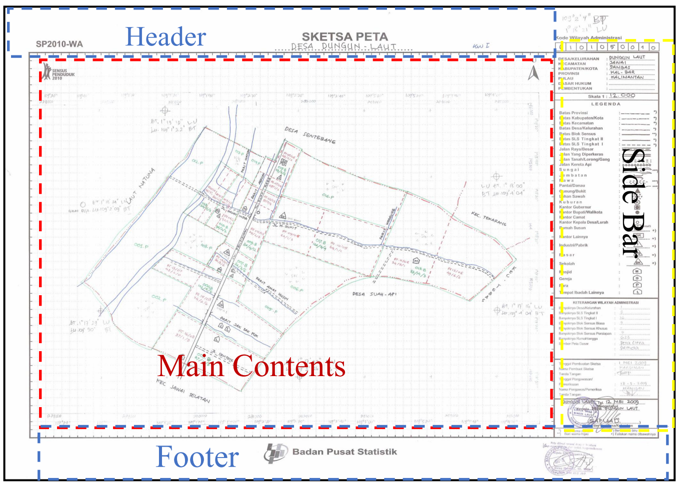

Figure 8: example of village sketch maps of population census

3.5.2 Georeferencing the village sketch maps without coordinates system

Village sketch maps are products of mappers' cognitive maps in which observation is used instead of measurement. Therefore, the information represented in sketch maps is typically distorted, schematized, incomplete, and generalized (Schwering et al., 2014). Therefore, before digitization, the sketch maps should be georeferenced to put it in the right position on existing metric base maps. As aforementioned, village sketch maps are made using pre-existing base maps: satellite image with coordinate systems, map with a coordinate system, and statistic sketch maps without coordinate system (BPS, 2009). For the first and second type, the coordinates can help. Meanwhile, for village sketch maps without a coordinate system, they can be manually georeferenced based on shapes and segments in the sketch maps.

Appropriate transformation method is required to reach good accuracy in georeferencing. There are many methods for georeferencing. For example, in Quantum GIS (QGIS), there are seven transformation methods available in the application.

From all seven available transformation methods, Helmert method gives higher accuracy as well as simplicity. Therefore, this method is recommended for the transformation. Mathematically the Helmert 2D transformation described as:

(Equation 1) $$\begin{bmatrix} X \\ Y \end{bmatrix}^B = \begin{bmatrix} T_x \\ T_y \end{bmatrix} + s \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} X \\ Y \end{bmatrix}^A$$

Scale (s) in the transformation is unitless. This type of transformation method works better in this case because the method as seen from the mathematical description, only rescaling and rotating the images. Since the village sketch maps mostly developed from previous existing maps, the rescaling and rotating are the only needed techniques to fit with metric base maps.

3.5.3 Digitization and alignment.

Digitization is a process of transforming the sketch images into a metric geodatabase. Digitization should be completed one by one for each village sketch maps. Further, because the information represented in the village sketch maps are typically distorted and schematized, alignment is required, otherwise, the maps will highly deviate.

The first step for alignment is putting all developed base maps into one bigger frame. It can be by sub-districts or multiple villages. In this case, because it is assumed that the villages boundaries are correct, the newly digitized base maps are combined on multiple villages. All RTs are firstly aligned into their corresponding villages and then aligned within each village according to the sketch maps proportion. This simply mosaicked all the digitized RTs boundaries.

Several geodatabases can be used for the alignment. Existing metric base maps obtained from local for instance, are very helpful. The newly digitized base maps aligned following the existing metric base maps and should be in this order in its priority. The existing metric base maps are:

1. Administrative boundary base maps, including village administrative boundaries, sub-district administrative boundaries, regency administrative boundaries.
2. Databases of the location of government buildings, facilities, offices, and other landmarks.
3. Geodatabase of roads, railways, and other infrastructures
4. Geodatabase of rivers and waterlines.

The order means, the digitized RT boundaries firstly aligned following existing administrative boundaries, then aligned to make sure landmarks such as education buildings, health facilities, and other landmarks fall into corresponding RTs as indicated in the village sketch maps, and later follow the roads and water lines.

The administrative boundary becomes the first order so that the new base maps can be mosaicked into villages properly avoiding overlaps. It is the frame for all of RT boundaries in a village. Landmarks are the most accurate way for mappers to locate the positions of RTs. Therefore, they should be in high order to locate RTs. Roads and other networks of infrastructures are objects for locating RTs position but tend to be distorted, schematized, incomplete, and generalized.

Rivers and waterlines are also geographical objects for locating RTs similarly to roads. However, it can be assumed that roads are more accessible to mappers. The shapes and positions of roads should be more familiar to mappers; therefore, they should be prioritized before rivers and waterlines.

Unless the village sketch maps are drawn carefully following accurate maps or satellite images/aerial images then the order is less important but to ease the process.

Illustration of the alignment procedure can be seen from pictures below:

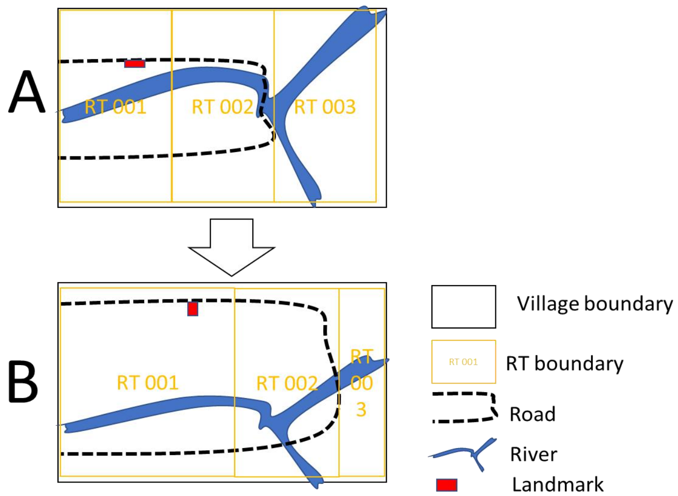

Figure 9: illustration of alignment with landmark, road, and waterlines

A is village sketch maps after digitization into a geodatabase where RTs boundary just follow the sketch map. B is RTs boundary after alignment where four required existing metric base maps are followed. RT 001 becomes larger as it follows the position of a landmark in the existing metric base map. RT 002 move to the right to follow the road' edges, and RT 003 narrowed as the consequence.

In a case where roads are unavailable, the alignment should follow the next order (rivers). As illustrated in Map C, RT 002 narrowed to follow the river's junction, and the rest of the area is given to RT 003. Meanwhile, if a landmark is the only alignment tool, the first step is to make sure that the landmark falls proportionally into the correct RT as indicated by the village sketch map. Later the other RTs will proportionally share the rest of the area.

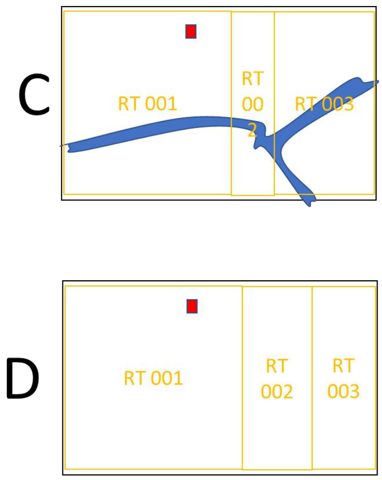

Figure 10: Illustration of alignment with landmark and road (C) and with landmark only (D)

3.6 Data model for using RTBM as a geocoding tool.

In this study, the new developed RTBM as a spatial data infrastructure was applied as geocoding tool for mining and analyzing spatial data from the collected databases. The relational model of the data can be seen from below diagram. The data were collected and compiled as a new database in which RT's unique identification numbers were used as a primary key.

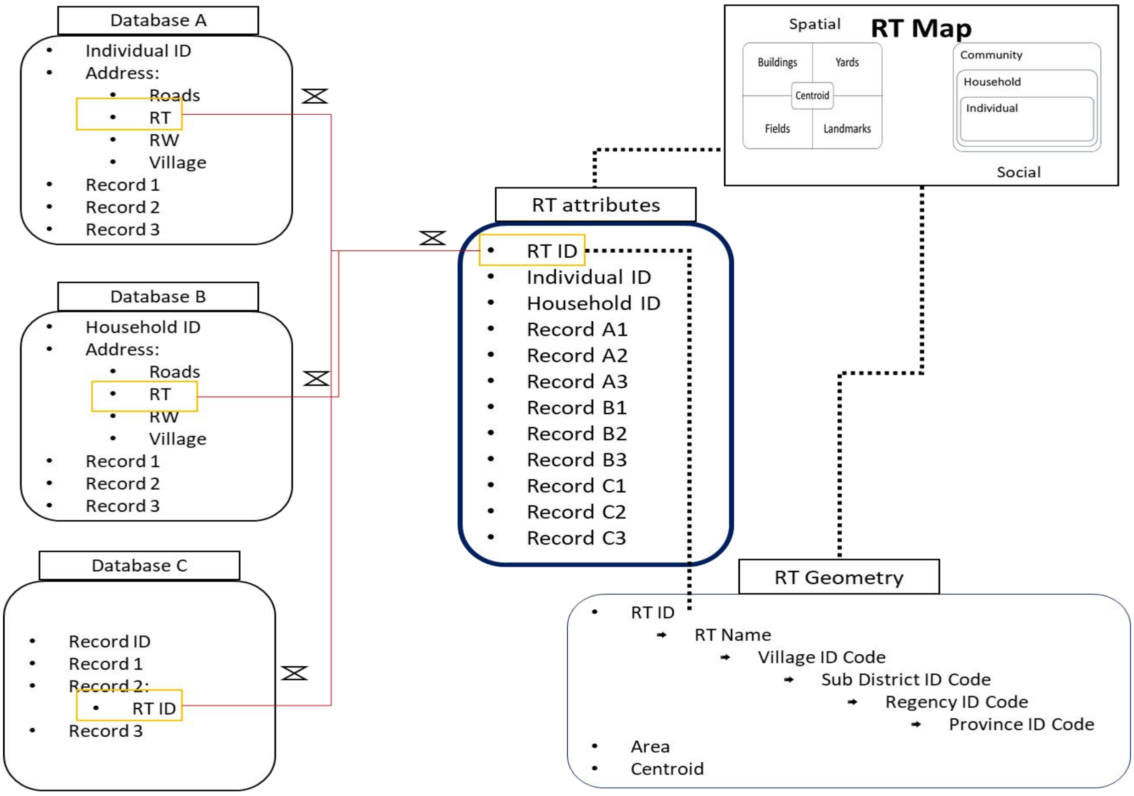

Figure 11: data model used for linking the databases and the BM

Based on the fact that it is the smallest administrative unit, RTBM should give a higher spatial resolution. Therefore, it is useful for coping with Modifiable Areal Unit Problem (MAUP). MAUP is a biasing effect in density analysis commonly happened on a larger scale of GIS analysis. Meanwhile, despite in principle, RT is a population-centered administrative unit instead of territorial one, the relationship between population/social components and geographic/spatial components of an RT can be drawn as figure 12.

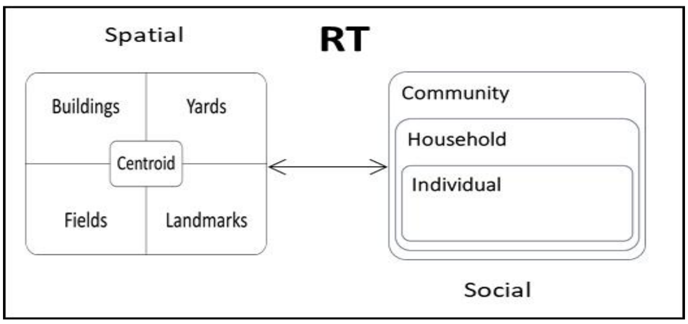

Figure 12: the relationship between spatial and social components of an RT

RT is a polygon in shape; therefore, a centroid exists. Centroids are helpful for spatial analysis considering uncertain legal boundaries. Buffering, for example, can be done using centroids of the RTs. Buildings are houses and other constructions where people live or do their activities. Some buildings have a yard which is open space complementary to the buildings. Sometimes, open space such as agricultural fields closely accessible to the population in an RT identified as a territorial area of corresponding RT. While landmarks can be used as unique objects to identify an RT territory.

The population is the members of an RT that can be analyzed in three levels; individual level, household level, or community level. In an analysis, spatial aspects and social aspects of an RT are exchangeable depend on the focus of analysis. For example, RT's area (centroid) can be used as a representation of its population position against a deforested area. Meanwhile, individual health records can be used as a representation of water pollution in an RT's territory where she/he lives.

4. RS ANALYSIS FOR MONITORING DEFORESTATION OF TROPICAL PEATLAND.

4.1 Land cover changes from 1995 to 2016 in Sebubus Forest: a case study

Sebubus Forest is located in northern part of Sambas regency. It lies between two water systems; Sambas River and Natuna Sea. The protected forest is surrounded by several villages that have mostly been existed since pre independence. For long time, the tropical peat forest remained save from exploitation because it is a deep tropical peatland in which agricultural practices are hardly done. However, recently the forest is getting attractive to local people and occupation slowly penetrate beyond the forest borders.

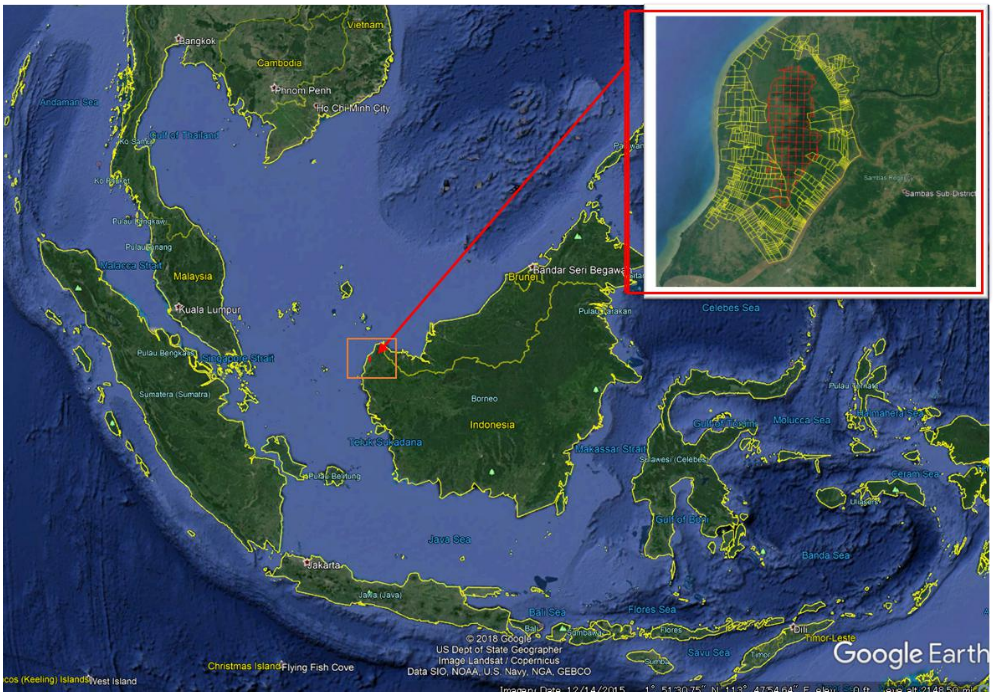

Figure 13: sebubus forest in indonesia map depicted from the Google Earth

Sebubus forest is legally enacted as a *productive forest*/ Hutan Produksi (HP) based on Indonesia regulation (Decree of Minister of Forestry Number 733 Year

2014/*Keputusan Menteri Kehutanan Republik Indonesia Nomor: SK.733/ Menhut II/2014 Tentang Kawasan Hutan Dan Konservasi Perairan Provinsi Kalimantan Barat)*. It has an area as large as 14.501 ha. The peat dome is categorized as deep peat soil (more than 6 meter depth) (Balitbang Pertanian, 2011).

The forest is located between Natuna Sea on the west and Sambas River on the east. Surrounded completely by paddy fields and local agriculture land, which benefitted from the peatland' ecosystem, the forest is a unique peatland area but also important for the surrounding communities. Vertical perspective of the forest can be understood from figure below.

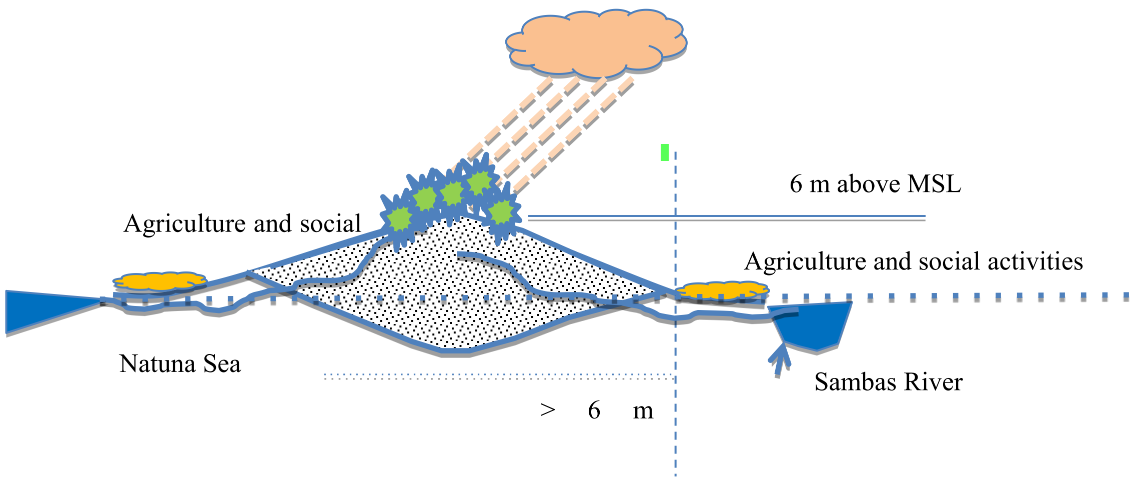

Figure 14: vertical perspective of Sebubus Forest

4.1.1 Landsat images as data for land cover changes analysis

Landsat Images archive were downloaded from USGS website using GloVis application. The research site falls within Path 122 Row 59 following World Reference System-2 (WRS-2). There are images span across time which is started from 1987 until 2016. Images are selected manually based on afore mentioned criteria.

Targeted scenes for analysis are aimed by interval of five years started from 1995. The objective is to detect dramatic changes in land cover of Sebubus peat forest to clarify the deforestation sequences. However, since no analyzable image is collected for year 2010 and 2015, it was decided to use data from 2009, 2013 and 2016 as replacement. Scenes are prioritized to be acquired between June to August in particular year because it is the time in which usually water log in peat soil is in its minimum existence. Exception is for 1995. The scene for this year is acquired on October since other scene in that year hardly analyzed.

Below are detailed scenes of Landsat imagery from Path 122 Row 59 that were analyzed:

Table 2: list of Landsat imges processed in the analysis

Year	Lansat Scene ID	Date of Acquisition
1995	LT51220591995300BKT00	1995-10-27
2000	LT51220592000234BKT00	2000-08-21
2005	LT51220592009210BKT00	2005-08-03
2009	LT51220592005215BKT00	2009-07-29
2013	LC81220592013173LGN00	2013-06-22
2016	LC81220592016182LGN00	2016-07-09

Source: (Muriadi & Yan, 2017)

4.1.2 Classifying the images

Selected images are processed using application ERDAS Imagine 2015 and ArcGIS version 10.2. Atmospheric correction was done using ERDAS Imagine 2015. Atmospheric correction is important for removing the influence of aerosols that primarily affect reflectance values in the shortwave length region of the electromagnetic spectrum [11]. Unsupervised classification was also conducted using ERDAS Imagine 2015. Meanwhile, Arc GIS 10.2 was applied for further analysis particularly to measure and define the land cover changes as well as data management.

Land cover is classified into four categories; Water/cloud, Bare Land/Agricultural Land, Shrub/Agricultural Land, and Forest. Water or cloud is defining existence of streams or water log in the peat soil. As it is well known peatlands are originally water logged all year long (Hairiah et al., 2011). However, it is common that some area on peatland may water logged only during particular time. Bare land is cleared land which often occurs when people begin their early stage of agricultural process in peat soils. It also can be happened after severe wild fire. Shrub is land area in which small trees start growing (woody plants usually less than 6 meters tall). Peatland usually quickly covered by shrub after land cleared. Mostly within one year, abandoned peatland will begins to be covered by shrub. Meanwhile forest here is group of big trees (more than 6 meters tall). Trees on peatlands mostly grow rapidly with high density. In some extent, trees in peatland can grow up reaching 180 meters tall.

4.1.3 Land cover changes in Sebubus Forest as detected by RS analysis

Image from Landsat Scene in 1995 indicates that Sebubus peat forest was relatively well maintained except in several parts around its boundaries. From image process it can be classified that around 80% from total 14.501 ha forest area is still covered by forest in 1995. While shrub, which comprises of around 13% of the area, mostly occupied its western boundary and edge of its southern part. It is likely that local communities did some agricultural activities in the peat soil as lands for livelihood were getting scarce for people of Jawai Sub District and Tekarang Sub District. Jawai Sub District in particular has higher density with limited land for developing its agriculture.

By 2000 or five year later, almost there was no significant change on land cover in Sebubus Peat Forest. Only some lands clearing was detected. Table 2 shows that from 1995 to 2000 there has been an increase on Bare Land from 955 ha to be 966 ha (see table 2). The table indicates land clearing happened on shrub and forest area. Forest decreased less than 1% during this five-year interval.

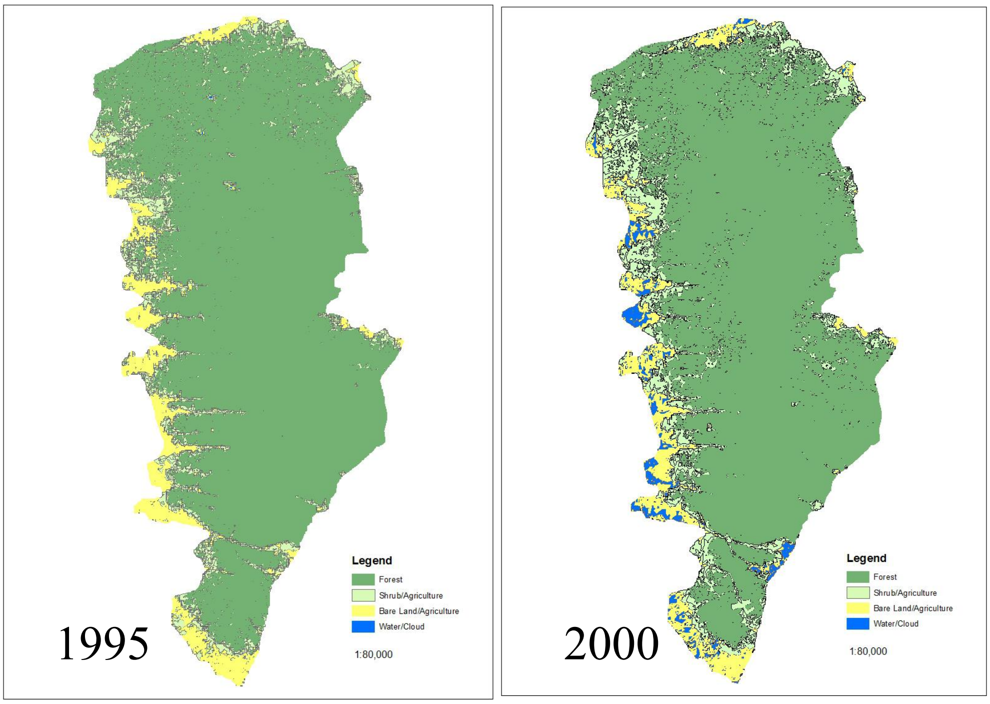

Figure 15: results of Landsat image analysis for the year 1995 and 2000

In 2005, forest cover increased from its last five-year condition. It is apparently coming from shrub which grew higher to be forest. Bare land was decreasing as well. However, Dramatic changes began within period of 2009 until 2013 where forest was left only 68% from its total area. By 2016 only around 12% of the forest remained covered by forestry trees.

A huge land cover changes happened from the western and northern part of the forest. Even though some bare land recovered back to forest on southern part, it cannot compensate to land cover change in western and northern part. In 2005, Landsat image data indicates only 1.24 % of the forest area can be classified as bare land. However, in 2009 bare land had occupied 22.53% of the total area of the forest.

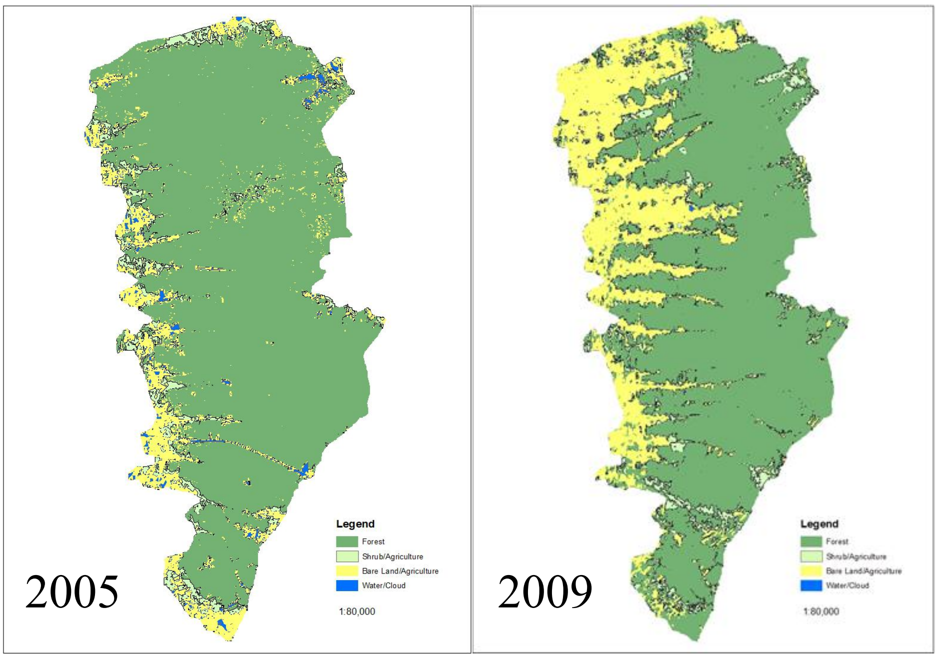

Figure 16: results of landsat image analysis for the year 2005 and 2009

Rapid increase of deforestation in Sebubus Forest continued in 2013. It even came from all direction except from eastern part. Agricultural activities reach deeper to the center of the forest and began to occupy the dome of the peat. Canals and roads apparently developed crossing from the west to east border of the forest.

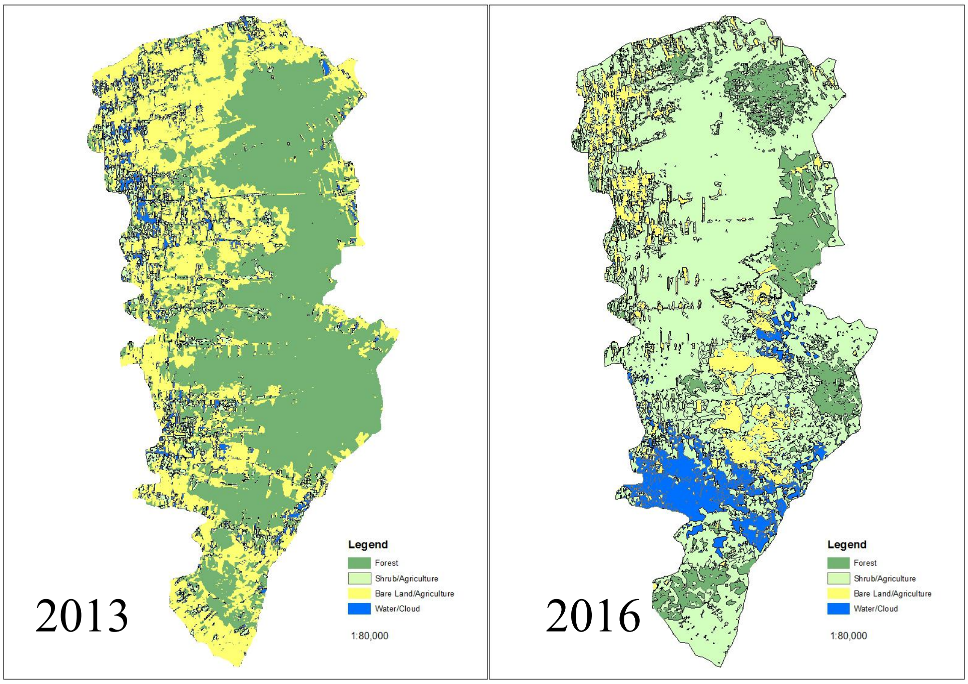

Figure 17: results of Landsat image analysis for the year 2013 and 2016

By 2013, only half (52.87%) of the tropical peat forest area remains covered by forest. Bare land or agricultural land occupied large area. Bare land indicates massive land clearing during this period in the forest area. The image data indicates 35% of the forest was bare land in 2013. That was a significant increase from 2009 which was 22.53%.

Table 3: Results of Landsat image classification

Land Cover/Year	1995	2000	2005	2009	2013	2016
Water/Cloud	**2**	**317**	**975**	**4**	**400**	**1,133**
	0.1	*2.18*	*6.75*	*0.03*	*2.76*	*7.82*
Bare Land	**953**	**966**	**179**	**3,267**	**5,079**	**1,287**
	6.57	*6.66*	*1.24*	*22.53*	*35.03*	*8.88*
Shrub	**1,895**	**1,674**	**1,470**	**1,429**	**1,355**	**10,404**
	13.07	*11.54*	*10.14*	*9.58*	*9.34*	*71.75*
Forest	**11,651**	**11,545**	**11,877**	**9,802**	**7,667**	**1,677**
	80.35	*79.61*	*81.90*	*67.59*	*52.87*	*11.56*
Total	**14,501**	**14,501**	**14,501**	**14,501**	**14,501**	**14,501**

By 2016, very little forest covered the peatland area. Shrub occupied most part of the forest. At least 71.75 % of the total forest area is covered by shrub or agricultural plantation. While forest covers only 11.56 % or at least less than 20% (considering some areas were covered by cloud on the scene). It is likely the cleared land between 2013 until recently that now growing to be shrub. A huge bare land on the center of the peatland area Rapid changes from forest to shrub in peat forest can result in serious vulnerability to wild fire. Experiences in tropical peatlands show that after transformed into shrub, peatlands are usually experiencing regular wild fire. Particularly when the peatlands are extensively drained. Shrub will trap oxygen which exacerbate ignition probability of tropical peat. The ignition probability is one of the important combustion properties of peat [5].

Land cover changes in Sebubus Peat Forest have been dramatically happened in recent decade. Pressures from local agricultural activities apparently contributed to rapid decrease on forest cover in the peatland area. Yet it is too early to blame local communities for the happening. There is a need to study more on the reasons behind sudden occupation by local agriculture to the peat forest. It is also interesting to find out the impact of the deforestation to the environment and local people that should have been benefited from existence of the peat forest.

On the other hand, this research shows that application of RS and GIS can be an important and usable tool for peatland monitoring as well as forest management. This application, yet have extensively used and applied on forest management, in fact can also contribute for social development planning purposes. Such as in the people's livelihood monitoring and management.

4.2 Monitoring AWs in the tropical peat forest using GEOBIA: case study in Sebubus Forest, Indonesia

4.2.1 GEOBIA for detecting and monitoring AWs in the tropical peatlands

In Indonesia, GEOBIA can be one of key tools for a future successful conservation and preservation management of tropical peat forest such as in the monitoring of the development of AWs in a preserved tropical peat forest, because it makes the effort easier and cheaper following the rapid development of technology in the acquiring high-resolution aerial imageries. However, it can only be happened if the method can be applied by proper users in the field. Current existing OBIA methods may still too complicated to be applied by the country's local government officers and grass root stake holders who involved in the peat forest conservation management.

Indonesia has the largest tropical peatlands in the world and acknowledged as globally significant tropical peatland ecosystems (Kristell Hergoualc'h et al., 2018). It is predicted around 14.91 million hectares tropical peatland spreading out in Indonesian islands such as Sumatera, Kalimantan, and Papua (Osaki & Tsuji, 2016). Recently, the carbon-rich ecosystem becomes an international concern due to rapid degradation and repeated occurrences of huge wildfires resulted in the release of CO2 at worrying amount into the atmosphere. One activity that greatly increases the rate of degradation and loss of tropical peat forests in Indonesia is the construction of AWs (canals and ditches), whether they are legal or illegal, in and near the forests and peatlands (Jauhiainen, Limin, Silvennoinen, & Yasander, 2016; Suryadiputra et al., 2005; Osaki & Tsuji, 2016). Meanwhile, strategy such as canal blocking may not fully compensate the negative effects (H. Ritzema, Limin, Kusin, Jauhiainen, & Wösten, 2014). Therefore, out of finding sustainable utilization techniques, monitoring the development of AWs is one of important factors for sustainability of the unique ecosystem.

In fact, exploitation of tropical peatland usually begins with the construction of any types of AWs. They are constructed in the tropical peatland to make the soil suitable for agriculture activities (Cooper et al., 2014; Evers, Yule, Padfield, O'Reilly, & Varkkey, 2017; S.E. Page & Baird, 2016; Rawlins & Morris, 2010); for transporting forest products (H. Ritzema et al., 2014; Suryadiputra et al., 2005); and becomes complementary structure in the road construction, in which their residual soil is usually used for elevating the road construction.

Whatever the reasons behind the existence, AWs contribute hugely to the destabilization of the tropical peatland's water table (Osaki & Tsuji, 2016). They drain tropical peat dome (Susan E Page et al., 2002) and change the nature of water flows which basically, owing to the convex character of tropical peat domes, flows in various directions as radial, widely spreadsheet flow rather than channel flow (H. Ritzema et al., 2014).

Currently, various efforts have been done to manage existing AWs in tropical peatlands, whether as part of sustainable agriculture activities or preservation actions (Padfield et al., 2014; H. P. Ritzema, Mutalib, Hassan, & Moens, 1998). Canal-blocking system, for example, has been widely introduced to curb adverse impacts, particularly after huge wildfires in 2015. However, this system may not fully help. Some parts of peatland should be free from any open exploitation. In this case, monitoring the human-made structures can be another option for preserving the carbon-rich ecosystem. It is also needed for further assessment of any possible effects on people and the surrounding agricultural area. Yet, this kind of effort has been given little attention. On the other hand, monitoring of AWs development should be involving multi-stakeholders for effective preservation efforts. A simpler monitoring method capitalizing current familiar technology hopefully can increase the participation of all related stakeholders.

RS techniques can be very helpful for landscape monitoring purposes. However, often the techniques are still too advanced and costly for local governments and other stakeholders at community level. Therefore, a simple workflow of RS approaches, such as of which uses open-geospatial data, incorporating local knowledge of the ground situation, and of which can be easily conducted by local governments' officials or other stakeholders, should be introduced. For example, in the monitoring of AWs in tropical peat forests, which are often very narrow, pixel-based RS may not appropriate. Besides, not all aerial imagery is appropriate for pixel-based analysis. With increasing High-Resolution Imagery such as of GE, OBIA should be better. However, the method can be too complicated for local government officials and grass roots stakeholders in tropical peat monitoring. Therefore, this research proposes such simplified method. Simplified GEOBIA can help local government officials and grassroot stake holders to capitalize increasing availability and quality of high-resolution aerial imagery for monitoring specific local objects important concerning their environmental landscape. GEOBIA is strongly associated with the notion of image segmentation but that is only one very typical geo-object-based delineation strategy (Blaschke et al., 2014). Many GEOBIA methods currently developed are focusing on automated segmentation and processes. Those techniques are likely too advanced for unskilled officials and stakeholders at community levels. On the other hand, plenty of existing useful local knowledge being ignored in most of developed GEOBIA. Therefore, incorporation of valuable local knowledge in the method is also important so that it can be really usable in the real implementation at the operational level.

4.2.2 Characteristics and development of AWs in Sebubus Forest

Results of stage 1

Table 1 summarizes information collected from fieldworks and ground surveys. It is found that in general, AWs in the area can be divided into three topologies. Those are the primary, the secondary, and the tertiary. While the way people construct AWs can be categorized into the traditional way and modern way. Primary AW, which is used for drainage of tropical peatland dome, flows water from peat dome into big rivers or sea. It is also used as the main transportation networks for accessing the area. Secondary AW is also used for drainage but mostly used to expand the reach of primary AW to a larger area. Meanwhile, tertiary AW is used to drain land lots and also used as territorial delineation (border).

Table 4: Generalized ground characteristics of AWs in the peatland areas in Sambas Regency

Typology	Traditional	Modern
Primary	Width: 1,5 – 2 m Depth: 1 – 2 m Construction Method: manual/traditional Direction: from peat dome to sea or main rivers Purpose: drain peat dome and collect water from secondaries and tertiaries Other: • parallel to the main road • the residual soil is stacked to elevate road (1-3m width) • the residual soil both sides stacked	Width: 2 – 4 m Depth: 2 – 3 m Method: Heavy equipment Direction: from peat dome to sea or main rivers Purpose: drain peat dome and collect water from secondaries and tertiaries Other: • parallel to the main road • the residual soil is stacked to elevate road (2-6 m width) • the residual soil on one side stacked
Secondary	Width: 60 – 1 m Depth: 1 – 1,5 m Method: manual/traditional Direction: from peat dome to sea or main rivers or primary canals Purpose: collect water from tertiaries Other: • Usually parallel with the main road but also sometimes parallel to secondary roads • the residual soil is stacked to elevate road (1-2 m width) • the residual soil is stacked one side	Width: 1 – 2 m Depth: 1 – 1,5 m Method: Heavy equipment Direction: from peat dome to sea or main rivers or primary canals Purpose: drain peat dome and collect water from secondary and tertiaries
Tertiary	Width: 30 – 50 cm Depth: 30 – 70 cm Method: manual/traditional Direction: from farmland to secondary or primary canals Purpose: control water of farmland and as borderline	n/a

On the other hand, three characteristics found to be appropriate to differentiate AW from NW. First, the width of the waterway's body in which AW always has a constant or regular width, contrary to NW's irregular one. Second, based on shape and turning tendency. AW tends to have straight shape with edged turns, while NW tends to swirl with curved turns. The third is related to the fact that AW in tropical peatland always parallels with the road. On the image (table 2), it can be seen that AW are always darker than the parallel road, both in color and grey image.

Results of stage 2

Digitization was conducted based on each available image for the site. There were seven images found for the Sebubus Forest. The images come from two sources: Digital Globe and CNES/Airbus. The images are in grey and colour.

Table 5: Image found from the google earth for the study area

No	Date of Image	Original Source	Characteristics
1	2009-04-03	Digital globe	Grey
2	2011-03-27	Digital globe	Grey
3	2013-10-02	Digital globe	Colour
4	2014-08-31	CNES/Airbus	Colour
5	2015-07-23	CNES/Airbus	Colour
6	2015-09-08	Digital globe	Grey
7	2017-27-06	Digital globe	Colour

Source: (Arip & Wanglin, 2019)

From the GEP, we found seven images correspond to the Sebubus Forest. We have digitized the images one by one to produce a geodatabase. The summary of the geodatabase can be seen from table 2. From the summary, it can be seen that a new image is not always available every year for a specific area. After 2009 for example, it required two years before a new image installed for the same area. It also happened after that. The next image found is for 2013. Meanwhile, in 2015 two images are found in the same area for the year. It means that irregularity characterizes image availability in the GEP. The irregularity seems happened to every area.

Despite the irregularity, table 3 suggests that the time-serial analysis for landscape changes like AW still probable to be conducted. Even though regular yearly changes cannot be traced back. Yet, the temporal analysis can be done and it is one of the advantages available on the application.

Table 6: Results of Digitization from Analyzed Images

No	Date of Image	New Detected AW	Description	Total Length (Km)
1	2009-04-03	22	First detection	35.62
2	2011-03-27	12	5 new, 7 continuation	42.66
3	2013-10-02	10	5 new, 5 continuation	25.97
4	2014-08-31	2	2 new	8.14
5	2015-07-23	8	4 new, 4 continuation	19.22
6	2015-09-08	5	4 new, 1 continuation	7.23
7	2017-27-06	12	12 continuation	25.99

Source: (Arip & Wanglin, 2019)

Results of stage 3

At the last stage, geodatabase obtained from on-screen digitization was transferred into QGIS and visualized into maps as depicted in figure 4. In the figure, results for the year 2015 are combined into one map so that only six maps are presented.

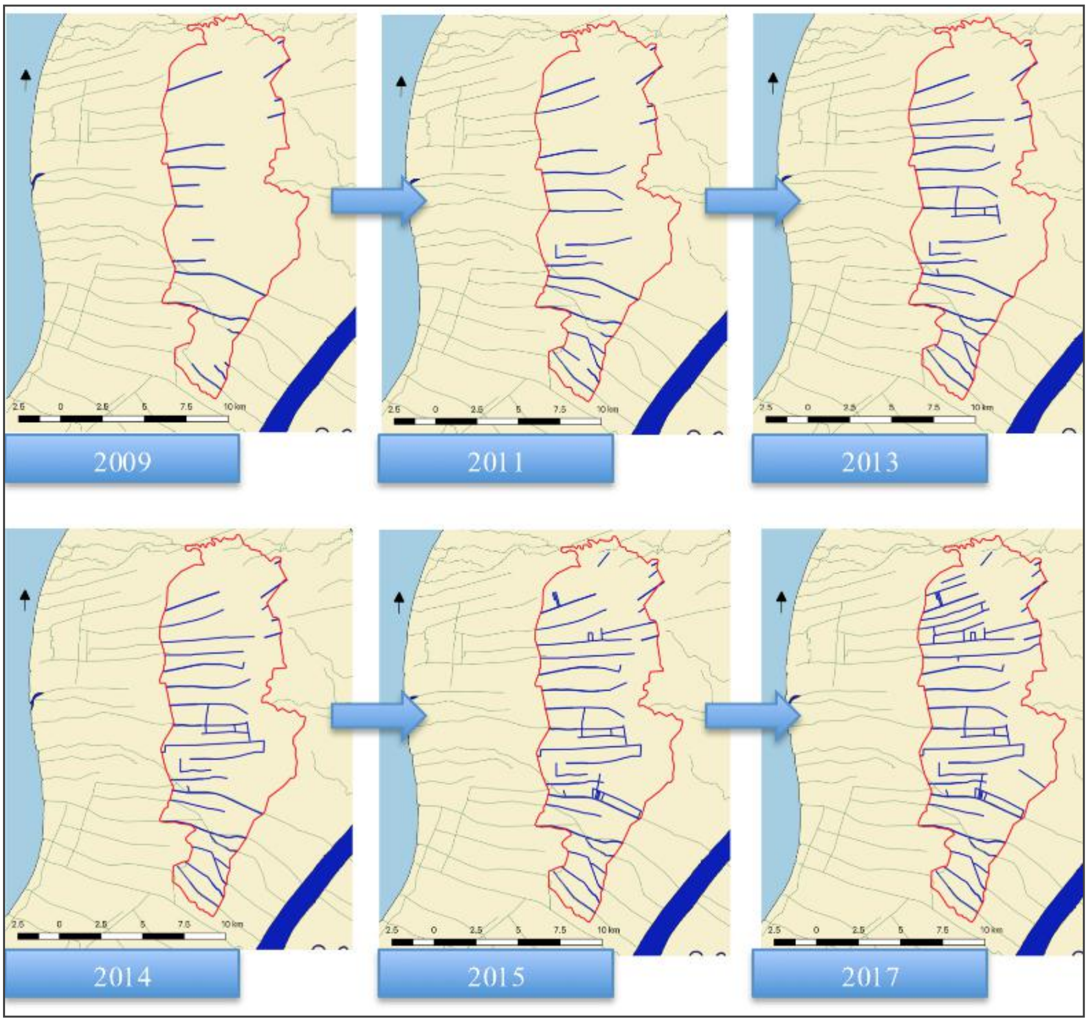

Figure 18: sequencial development of artificial waterways in the Sebubus Forest

Meanwhile, a very simple statistical results tool from QGIS application is presented in table 4. The summary shows a general statistic of the data. It shows that there are 66 objects identified as AWs from 2009 until 2017 with minimum length is around 260 meter and longest one is around 7.4 km. In total from 2009 until 2017 there has been 166.5 km AWs in Sebubus Forest.

Table 7: Statistical summary of the AWs

1	Analyzed field:	Length
2	Count:	66
3	Unique values:	59
4	NULL (missing) values:	0
5	Minimum value:	0.26
6	Maximum value:	7.69
7	Range:	7.43
8	Sum:	166.48
9	Mean value:	2.52
10	Median value:	2.04
11	Standard deviation:	1.87
12	Coefficient of Variation:	0.74
13	Minority (rarest occurring value):	0.26
14	Majority (most frequently occurring value):	0.51
15	First quartile:	0.77
16	Third quartile:	3.62
17	Interquartile Range (IQR):	2.85

Source: (Arip & Wanglin, 2019)

Based on the above results, there are at least three interesting points to be discussed. First, related to the trends and characteristics of AWs development in Sebubus Forest. Second, related to the use of GEHRI for monitoring of natural resources. And the third, related to the implication on tropical peatland management.

A. Trends and characteristics of AWs development in Sebubus Forest:

Based on its status as production forest (Ministry of Forestry, 2014), very limited activities allowed in the area (The President of Republic of Indonesia, 2016). Local people can, in a very limited way, harvesting forest products for their livelihood. The activities should not change the nature of the forest. Agricultural activities should be strictly prohibited. However, the results of this study show contrary condition. Despite in a limited extent only, some AWs have already existed in the forest since 2009. Hard to detect when actually the infiltration began, but there is a high tendency that AWs have been developing mostly from the western part of the forest.

Based on local government databases, there are several villages on the western part of the forest. By 2011, almost all villages in the western part showed new construction of AWs. Meanwhile, development from the eastern part remained stagnant. On average, there have been 20.81 km of new AWs developed in Sebubus Forest every year from 2009 until mid of 2017. Around 8 new systems were built every year with an average length of around 2.5 km each. That is a rapid development with steady increase year to year.

Until 2011, mostly only primary canals dominated the development. It can be seen from the direction of the lines that directly flow from central part of the forest to main water systems (Natuan Sea in the West and Sambas River in the East). By 2013, some secondary canals were developed. This indicates that the AWs have agricultural purposes. Secondary canals usually aimed at expansion of land occupation in the peatland (Vonk, 2011). Secondary canals are used to expand the occupancy area while opening access for more drainage systems.

In general, detected AWs in the forest indicate that they are the continuation of previously existing agriculture drainage systems in surrounding villages. It means that the utilization of the tropical peatland likely related to the increasing demand for new agriculture land site. The position from one waterway system to another varies from 500 to 1000 meters, which also shows that they are most likely for agriculture purposes. Based on an interview with officials of local agriculture department of Sambas Regency, commonly agriculture land site in Sambas Regency is around 40 to 50 meters wide and 500 meters long or 2 to 2.5 hectares each. On the other hand, the variation of distance from one system to another and the formation give a clue that mostly the AWs developed in the forest are of the local community's agriculture purpose. Since big plantation companies usually develop a very neat and uniformed design.

The development of AWs was still in the same tendency until 2014 in which primary canals developed deeper. They were crossing the peat dome area. However, tertiary canals were detected in 2015 and the primary canals were completely crossing the between two sides. By 2017, the AW networks totally covered the forest. A condition that is almost irreversible for the ecosystem health. At this stage, massive AW networks almost certainly capable to drain the whole water table of the peat forest in short period.

B. The implication on the use of GEHRI for landscape monitoring:

GE is an open access application increasingly popular and widely used for various purposes. It is a simple application with powerful capabilities. The high-resolution images in GE provide methodological development opportunities for various research and analysis approaches. Although the best image quality in GE is found mostly in highly populated areas and important landmarks (Harrington et al., 2017), this study found that its use for analyzing unpopulated areas such as forests is still a great opportunity.

With an appropriate approach, GE is a simple way to obtain geodatabase. Its HRI is developing following advancement in satellite data technologies. It is opportunity for different fields. In natural conservation and preservation domain, researchers are developing methodological approaches for its use properly. More accurate and robust techniques are important. However, simple approaches are in some extent required and beneficial. As presented in the above results, a simplified approach gives very clear images of how AWs have been developed in a tropical peat forest. Two key points on the use are on understanding the object's characteristics at ground level and understanding objects semantics at image level as well as the characteristics of the images themselves.

Good understanding and enough information on characteristics of the object at ground level ease the process to identify the object on images. Existing knowledge and information at ground level can be an advantage for local stakeholders in the natural resource preservation and conservation efforts. Because local people usually have enough knowledge and information related to their landscape. In fact, many objects have very local characteristics. Unpaved roads in Kalimantan's tropical peatland, for example, are generally elevated higher than surrounding soil compared to unpaved roads in mineral soil in Java.

On the other hand, despite being packed in one application, images on GEP have different characteristics for different locations. Because the images in the application are basically come from various original sources as we can see from Table 2. Therefore, understanding the characteristics of the images for a specific area is important for better object's classification.

C. The implication to the tropical peatland management

The implication of this work to the tropical peatland management can be seen from two perspectives. First, on the substance of the results in which AWs are detected infiltrating to the forest in an irreversible level, in spite of the fact that the forest is a preserved forest. The results show that the infiltration was just rapidly happened during the last decade. As presented before, local government data depicts that before 2009 the forest was relatively free from AW, particularly on its peat dome. However, during the last decade, the infiltration was so rapid that almost all parts of the forest have been exposed to AWs.

There are several indications that the local people are involved in the development. Why do people do such suicidal development is not part of this work to answer it. Anyhow, this is a challenge for the preservation of the tropical forest. At a glance, the results tell us that tropical peat forests surrounded by local communities seem to be vulnerable to traditional agriculture activities. In consequence, people around the ecosystem are very vulnerable to adverse impacts. While stakeholders may fail to recognize the vulnerability. The community may be impacted severely

This suggests that a new approach to tropical peatland management is required. Enacting law alone may not enough to preserve the forest even if it is very precious and may influence the lives of many. Law enforcement is also unlikely to be a sole solution because those involved in the development are communities in large number. Instead, a participative forest management may be better.

Second, on the perspective of tropical peatland monitoring methods, a simpler approach can help not only local governments to monitor protected tropical peat forest in their administrative area, but also helps other stakeholders such as Non-governmental Organizations (NGOs) and communities interested in natural resources protection and preservation. With the simplicity, the non-professional researcher can conduct appropriate analysis, at least to recognize problems that often hide in blurring socio-environmental issues.

Despite having been enacted as preserved forest, Sebubus forest has experienced massive open exploitation in the last decade. Patterns and trends of development of AWs in the forest indicate that demand for new agricultural land sites may behind the rapid penetration of AWs into the forest. This research does not going into deep analysis on the impact of the open exploitation to the people and surrounding agriculture activities. However, considering the importance of the forest to the surrounding agriculture and communities, the destruction of the forest may certainly sooner or later bring about severe consequences.

Results of this study also suggest that a new approach of tropical peatland preservation and management is needed. The ecosystem is very vulnerable to human pressures. It is often, recognizing the vulnerability is far from simple, and understanding its cause is even harder (Yan & Galloway, 2017). Monitoring the ecosystem using the simple approach in which non-specialist researcher can do it should be developed. As presented in this paper, using simple workflow utilizing open geospatial data such as GEHRI, we can detect and monitor the development of human construction in the protected forest. The simplicity of the workflow enables almost everyone to do natural resources monitoring. Using free familiar applications and incorporating it with available local knowledge and information should be able to ease the involvement of stakeholders at the grassroots level. Meanwhile, using GEHRI with a simple process as presented in this study may not give a deep analysis. Yet it is enough to recognize a shadow of vulnerabilities, both on the natural resources and the communities.

5. MINING PAD FOR SPATIAL BASED RESEARCH AND ANALYSIS

5.1 Developing RTBM as new SDI's Feature for Mining PAD: Case Study in Sambas Regency, Indonesia

5.1.1 Data for the Base Map Development

For this case study, as many as 31 village sketch maps of Indonesia Population Census 2010 were collected and processed. The 31 villages are chosen for they are surrounded Sebubus Forest and expected to have direct access to the forest through its hydrology system.

The data were obtained from local Statistic office in Sambas Regency of West Kalimantan Province, Indonesia. The sketch maps were obtained in scanned image format. Below is an example of village sketch map of population census 2010:

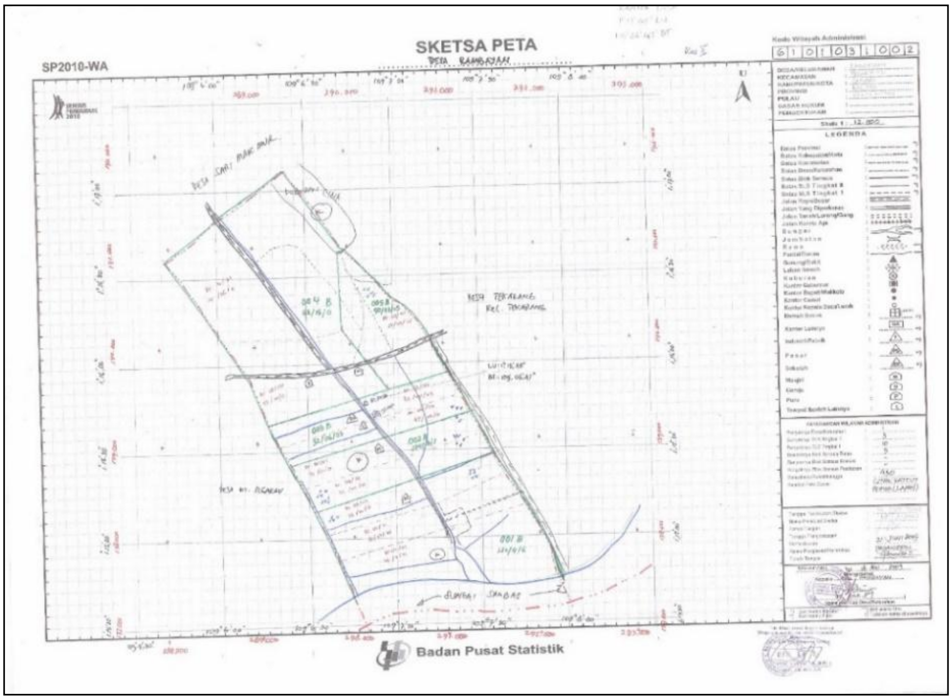

Figure 19: village sketch map of population census 2010

All of the 31 village sketch maps contain coordinate reference. That makes the georeferencing process easier.

5.1.2 Tools and methods

Quantum GIS (QGIS) was used as the application for processing and analyzing the data. This application was chosen because it is free open software. Hopefully, other researchers or local officials can easily download it from the internet thus make them easy for replicating this work.

Village sketch maps are products of mappers' cognitive maps in which observation is used instead of measurement. Therefore, the information represented in sketch maps are typically distorted, schematized, incomplete, and generalized (Schwering et al., 2014). Therefore, despite having coordinate references on each village sketch maps, alignment is required after digitization to transform the sketch maps into a more realistic and accurate metric maps.

The first step for alignment is putting all new digitized maps as one mosaicked base map. All RTs are firstly aligned into their corresponding villages and then aligned within village according to the sketch maps proportion.

There are several geodatabases used for the alignment. They are existing metric base maps obtained from local government of Sambas Regency. The newly digitized base maps aligned following the existing metric base maps. The existing metric base maps are:

1. Administrative boundary base maps, including village administrative boundaries, sub district administrative boundaries, regency administrative boundaries. These databases developed in 2006. There is no clear explanation on definitive year to refer for these base maps.

2. Education buildings and facilities database. This database was developed in 2008 until 2009
3. Health facilities, this database also developed in 2008 until 2009.
4. Geodatabase of rivers and waterlines obtained from Local Development Planning Agency of Sambas Regency. These geodatabases seemingly a result of survey conducted in 2003 until 2005
5. Geodatabase of roads also obtained from Local Development Planning Agency of Sambas Regency. These geodatabases also seemingly a result of survey conducted in 2003 until 2005

5.1.3 The new developed RTBM.

New Developed RTBM as a result of the process in this study has been published as an open dataset on Mendeley Data (Arip, 2019). As it was expected, at first stage, digitized village sketch maps resulted in highly deviated features. There are three sources of deviation. First, the deviation comes from transformation and the second, the deviation comes from changing village boundaries itself, that is when the village boundaries changed and cause differences between the sketch maps and the metric base maps. The consequence of the deviation is overlapping boundaries. However, it is important to understand that not all of the overlapping comes from digitization deviation. Some may come from territorial disputes.

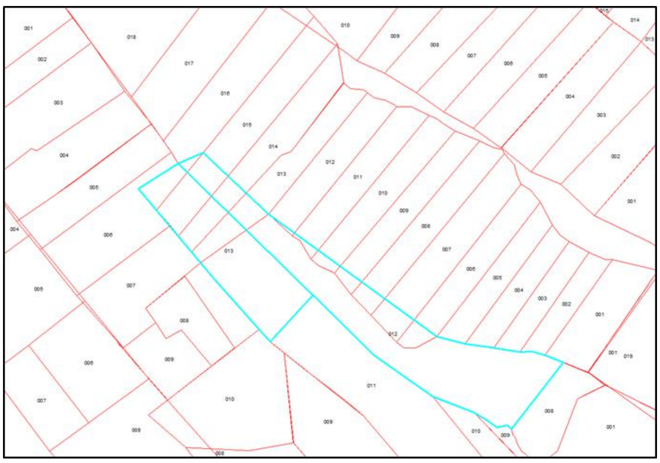

Figure 20: deviation as the impact of the sketch map

Statistical Summary of the base map can be seen from an output of the Basic Statistic process in QGIS as follow:

Table 8: statistical summary of the new base map

1	Count	458
2	CV	1.247
3	Empty	0
4	Filled	458
5	First quartile	20.9
6	IQR	66.3
7	Majority	10.1
8	Max	710.16
9	Mean	76.001
10	Median	47.44
11	Min	1.01
12	Minority	1.01
13	Range	709.15
14	Std_Dev	94.794
15	Sum	34808.470
16	Third quartile	87.2
17	Unique	456

For 30 village sketch maps digitized in this study, as many as 458 RTs were found. On average, the area of RTs is around 76 hectares per RT. With the smallest area is around 1 hectare only with the majority has 20 to 90 hectares area. The largest RT in this study reaches an extent of more than 700 hectares. This size is similar to a village in some densely populated areas.

The total area of all 30 villages is 59.280 hectares, but the total area of RTs in those villages is around 34.808 hectares. Therefore, there are more than 24.000 hectares area of the villages which are not associated with any particular RT. The blank areas can be a forest, agricultural fields, or just bare lands. For example, a big blank area surrounded by the digitized RTs shown on the map (Figure 6) is actually a protected forest. This forest has a size of around 15.000 hectares.

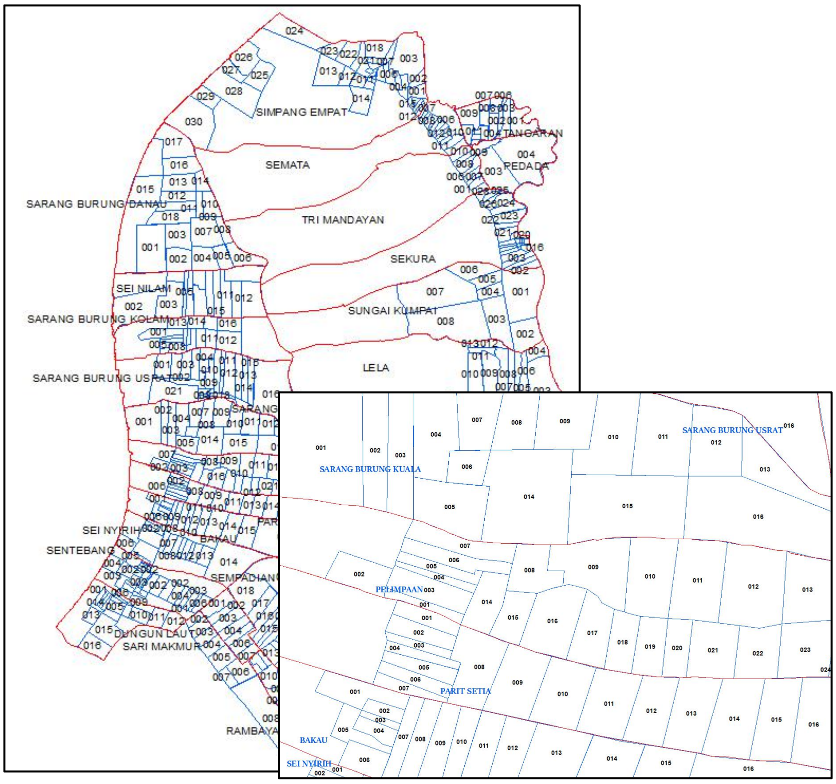

Figure 21: New developed RT BM after integration to the existing local government's base

From the above statistics, it can be figured out that the areas of RTs in the digitized villages are highly varied. The coefficient of variance (CV) shows that the area has almost 125% variability. At a glance, the variability occurs between rural and urban area. This can be resulted from the fact that RT is designed for specified numbers of households. For instance, in some municipality like Malang City in East Java, the government has regulated that an RT should be consists of 30 to 50 households.

Despite there is no regulation in the research site, the tendency shows a similarity. The specified numbers need smaller area in dense population like in urban area and larger in less populated like rural area. On average the area of RTs is around 76 hectares per RT. With the smallest area is around 1 hectare only and the largest can be more than 700 hectares. The variation means that in terms of geographical representation, RT cannot be seen as a custom size. On the other hand, from the above maps, some blank areas are figured out. The blank areas are forest or agricultural area and other space without population. Those blank areas mean that RT, despite its function as administrative area, is not perfectly dividing land territory of its upper administration. As consequence, using RT administrative area as PAD linking platform gives a unique geographical representation. That is the existence of some geographical area without representation or collectively represented. This can be a drawback, but also a strength.

5.1.4 Field surveys for accuracy assessment of the new developed base map.

In order to understand the accuracy and applicability of the newly developed base map, a field survey was conducted in which exact ground objects coordinates were collected. Coordinate of ground objects where RT's identity can be clearly defined such as house number and statistics stickers, border statues, and any other signs were recorded.

Figure 22: RT identification on house wall

Sample are categorized into three types: Random points of RT identification, Exact points of village border, and the exact point of RT border.

For the first type, as many as 53 samples were collected from 15 out of 30 villages. The results show that against digitized base map (before alignment), 51% of the samples fall within false RT meanwhile 49% fall into correct RT. The same samples put against aligned base map show that 75% fall into correct RT which is significant accuracy improvement.

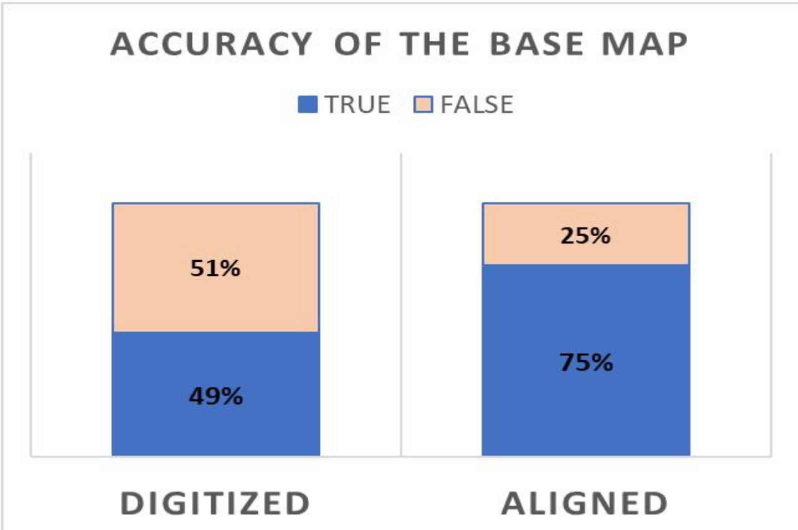

Figure 23: Improvement of the accuracy after alignment

For the second type, 24 samples were collected from 19 villages. Averagely, the borders on the map deviate around 529 meters from the sample points taken on the field.

Meanwhile, for the third type, ten samples were collected from eight villages and the measurement show averagely 45 meters deviation of RT borders on the map with a coordinate of collected points. All of the samples for exact point show highly accurate relative position to landmarks, roads, and water lines (below 10-meter accuracy which is the precision of used GPS tool).

5.2 Using RTBM as a geocoding tool to link PAD with GIS: Case Study in Sambas Regency, Indonesia.

In order to understand the usability of RTBM as new spatial data infrastructure to link PAD with GIS, a linkability analysis was conducted. Data for linkability analysis are un-aggregated databases from local government offices. A framework for linking PAD to the RTBM is follow:

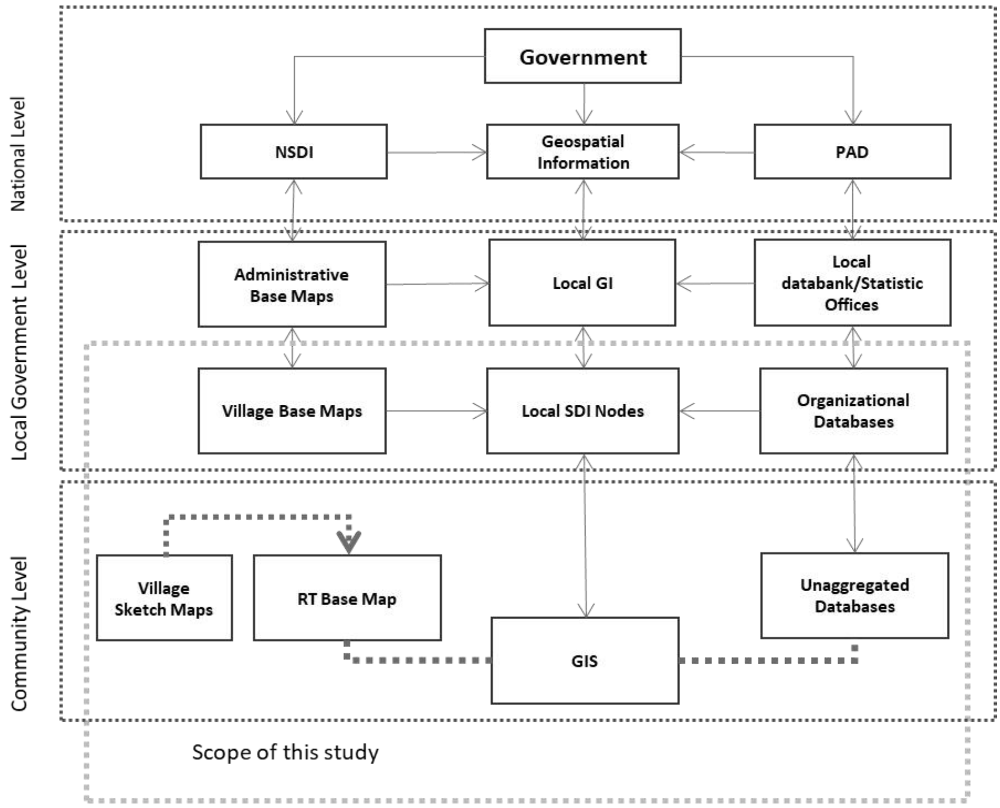

Figure 24: conceptual framework for linking RTBM and un-aggregated databases

Two main challenges on spatially linking government's unaggregated databases are the absence of appropriate base maps and inadequate existence of geolocation identifiers in the databases. To address these challenges, this study investigates the linkability of government's unaggregated databases to the smallest administrative area in Indonesia called RT. The investigation is derived from a framework as shown in Figure 24. GI is produced by linking PAD with SDI. This system downs from central government into lower levels of government structure until the community or the individual level.

An un-aggregated database is a database in its original form. The records are not yet compiled or aggregated Aggregation of PAD is usually based on administrative systems. Un-aggregated databases can be collected from different local government offices.

Geolocation identifiers in un-aggregated databases are usually in a very exact location such as landmark positions, house numbers, road's names, and the smallest administrative units. However, the smallest administrative units are the most often used and formally required in most administrative affairs.

Because the databases are relational databases, data are examined and analyzed using common SQL process. In this study, the focus is to investigate how RT exists within the records. The linkability of the records to the RT as a geolocation identifier is determined by how RT can be appropriately related to the records in the databases. In other words, a record is categorized as un-linkable to the RT if the data row finds no RT on its columns or RT cannot be appropriately identified whether because of mistyped, unknown RT identity (numbered 0), left blank or just unavailable (N/A).

For linkability assessment, four un-aggregated databases were collected and investigated.

Table 9: List of databases for linkability analysis

No	Database Name	Original Administrator	Database Platform
1	Health Insurance for the poor	Dinkes	Microsoft Excel
2	Population Registry 2015	Disduk	Oracle Database
3	Development proposal 2015	Bappeda	Microsoft Access
4	Land Taxation 1988-2017	Bakuda	Oracle Database

The four databases are a representation of PAD categories as described by Wallgren & Wallgren, (2014). First, Population registry and Health insurance database are actually statistical data produced by an authority for their own purposes. Land

Taxation is a database containing variables which are legally important. Meanwhile, development planning proposals are a category of variables representing decisions.

From the four databases, only one database (database of development proposal 2015) is an open public database. Meanwhile, all other databases are protected by privacy and therefore the handling is carefully carried out.

Health Insurance for the poor is a database administered by the local health department. The database contains the identity of the beneficiaries of free health insurance for the poor program. Population Registry is a database from famous Sistem Informasi Administrasi Kependudukan (Information System for Population Administration). The database is a copied version obtained from the local Registry Office. In this database personal identities including the address of each individual registered as the citizen of Sambas Regency are recorded. Meanwhile, the development proposal database is a database contains the information of development projects proposed by citizens to the local government of Sambas Regency.

The three collected databases are for the year 2015 only. Meanwhile, one database named the Land Taxation Database has accumulated records for the year 1988 until 2017. However, the records are selected for 4 subdistricts out of 19 in the Regency. The subdistricts are Jawai, Teluk Keramat, Tekarang, and Tangaran. The limitations on the collected databases depend upon the administrators' issues, whether because of privacy matters or technical constraints.

1.1.1. Linkability of PAD to RT as geolocation identifier

There are 1,337,028 rows of records found from the four collected databases (see Table 4 below). In total, 94.63 percent of the rows are linkable to RT as geolocation identifier. Population Registry 2015 is the highest among others in linkability. 99.48 percent of the rows in the database directly linkable to corresponding

RT. Health Insurance for the poor 2015 which is the second highest, has 99.22 percent linkability. Land taxation database which is a collection of data from the year 1988 until 2017 has almost 83 percent linkability. Meanwhile, development planning proposal database for the year 2015 has only 27.06 percent.

Table 10: Results of linkability analysis

No	Name of the Database	Records	Missing link	Percentage
1	Health Insurance for the poor 2015	374,577	2,935	99.22%
2	Population Registry 2015	599,919	3,122	99.48%
3	Dev. Planning Proposal 2015	6,902	5,034	27.06%
4	Land Taxation 1988-2017 (4 sub districts)	355,630	60,750	82.92%
	Total	1,337,028	71,841	94.63%

Source: Arip, Wanglin, and Hirose (2019)

1.1.2. Linkability and approaches for using RT as a unit of analysis.

High linkability in the population registry is a very good opportunity for linking PAD. Because, it means all other population-based databases, as far as containing population-based records such as individual identification number or household identity number, can be linked to RT. This also means that RT and population registry can be an interchangeable platform for human-spatial/human geography analysis.

Another good point about population registry is that, despite administered by a local government institution, the database actually product of a national-scale information system. The system is known as SIAK (Sistem Informasi Administrasi Kependudukan/Information System for Population Administration).

Development planning proposals for the year 2015 has the lowest linkability because RT is not required in its application form. In this database, most of the records un-linkable to RT as geolocation identifier. Yet, around 27 percent of the records are linkable. With the percentage, there is a lot of spatial information can be gained from the database. Because the database is updated on an annual basis and contains a lot of records. With purposive policy, the percentage should be increasable.

Based on the result of the database analysis, there are two ways to cope with the un-linkable records. Distribute the value of the records to other linkable ones using a population-based approach is the first one. In this approach, the un-linkable records are proportionally distributed into other records based on population distribution. High linkability in the population registry as found in this study is a good point for this case. Because there are so many databases that actually linked to population data. As a consequence, even with the absent of RT information in the datasheet, a database can be linked to RTBMs as far as it is linkable to population database. Furthermore, the database can be spatially analyzed.

The second approach is the spatial distribution approach. In this approach, the value of un-linkable records is proportionally distributed to the other records based on their spatial share of RTs in their higher-level administrative unit. The second approach is basically the same approach as the normal linking of PAD using administrative boundary as the platform.

It is suggested that the best approach for analysis depends on the main interest of the research. If the research is more focus on human or population, then population-based distribution should be better. Meanwhile, if the research is more focus on spatial dimension or geographical issues, then spatial distribution should be better.

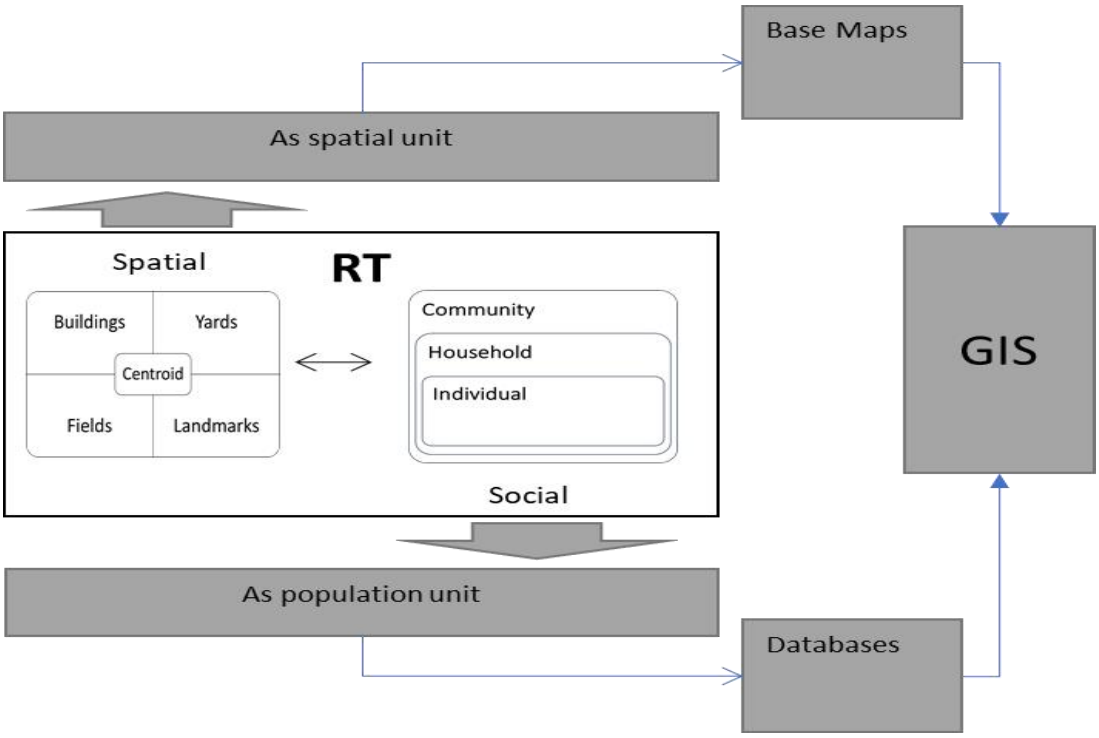

Figure 25: approaches for using RTs as a unit of analysis

1.1.3. Using RT as new layer of SDI to link PAD with GIS and lessons learned.

In this study, the new developed RTBM as a spatial data infrastructure was applied for mining and analyzing spatial data from the collected databases. The relational model of the data can be seen from figure 11. The data were collected and compiled as a new database in which RT's unique identification numbers were used as a primary key.

Example of the data visualization can be seen from Figure 26 and Figure 27. Figure 26 below shows the distribution of land registration tax in 2011. Data from databases were directly linked to the base map following the data model. Map B in Figure 26 is the distribution of land registration by RT, and Map A is the same data aggregated and linked to Village Boundary base map from Local Government.

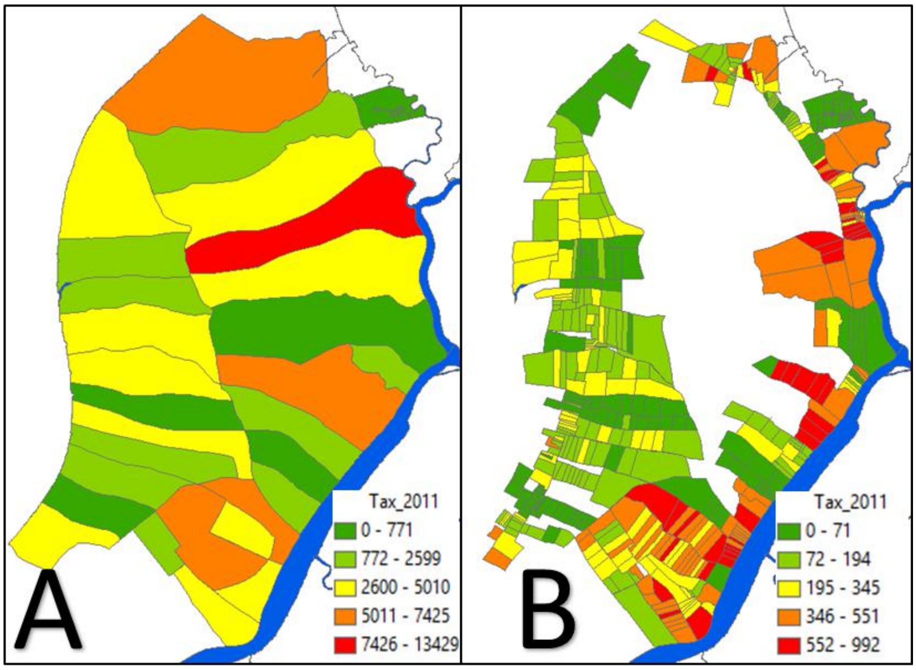

Figure 26: government village BM (A) with the new RT BM (B) applied on the same data

As aforementioned, the SABBM such as RTBM gives a higher spatial resolution. Figure 26 shows that using the base map, a different perspective of spatial visualization of data can be presented. Therefore, it is useful for coping with Modifiable Areal Unit Problem (MAUP). MAUP is a biasing effect in density analysis commonly happened on a larger scale of GIS analysis.

On the other hand, the land tax registration combined with population distribution presented in density maps give another understanding as can be seen from Figure 27. Using RTBM (Map B) shows a more realistic distribution than village base map (Map A) considering the existence of protected forest (red line) in the area. Therefore, using RTBM is more realistic for analyzing the relationship between social variables (Eg. population and tax) with deforestation in this case.

Better visualization of population distribution pattern in a spatial extent can also be depicted from Figure 27. For instance, how population tends to disperse over villages on the west part of the area and tend to concentrate on the east side, can be apparently distinguished from Map B in Figure 27. Using village as the unit of analysis, such pattern is hardly detected (Map A). The capability of detecting such tendency is important in studying various ecological dan spatial phenomena.

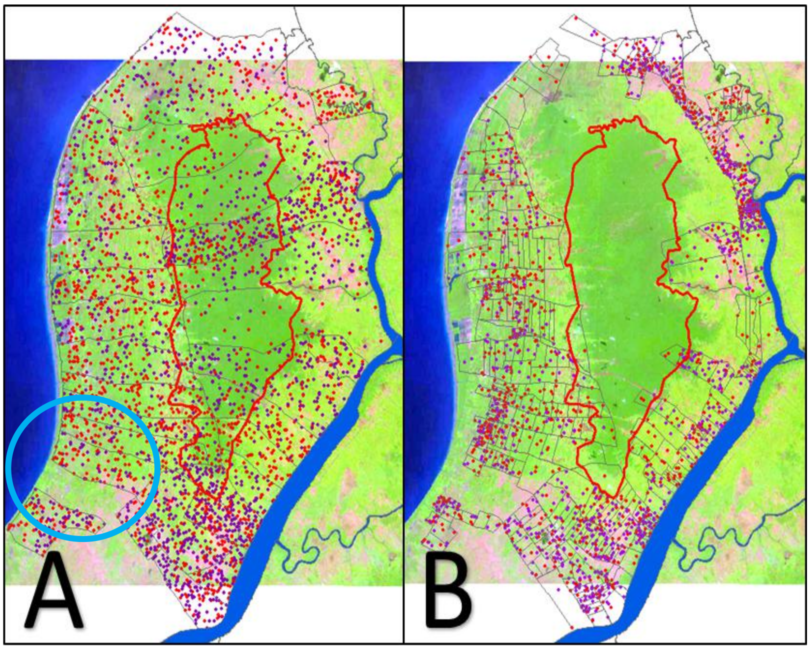

Figure 27:new land tax registration the year 2011 in density map visualized on village BM (A) and RTBM (B)

Meanwhile, despite method for the development of the base map from this case study is expected to be applicable nationwide considering the data uniformity, in some extent, use of the base map is unique for this case study. Use in other areas may need some modifications depends on local circumstances and research uniqueness. However, some lessons were learned from using the base map which is important. One of them is that there is a village where the RT's identity cannot be linked to the databases (see blue circle in Map A on Figure 14). The reason is that the RTs' numbering system on the base map is not in line with the databases. Names of RTs in the village were unique to RW (One level upper administrative unit). It should be unique to their Village which is used by the databases. It seems that while other villages adopted the numbering system before the made of the village sketch maps, the village did it later. The key lesson on this point is that the linkability of the data to the base map is not merely determined by the existence of geolocation identifiers in the databases but also by the base map itself. This is in agreement with missing links in the databases likely resulted from the establishment of new RTs. This case, despite unique for this study, may also happen in different areas in the country considering less attention given to RT mapping. In fact, this case supports the third condition for the usability of the base map as discussed in Chapter 2.2 above.

The other lesson learned is on using confidential data. Tax registration database and population registry database used in this study are public databases containing personal records protected by the privacy act. Using RTBM as shown in Figure 13 and Figure 14 indicates that the personal data can be de-identified and analyzed with less compensation of the spatial accuracy. In this study, the average size of RT is 0.04 % or 1/26 times smaller than the average size of villages. In other areas, it can be different. But it can be safe to assume that generally, the size can give a balanced value between spatial accuracy and personal privacy protection.

Finally, using the base map, there are many public databases containing confidential records can be mined and analyzed for various spatial based research and analysis as shown using the approach in mining tax and population registry in this study. Rapid improvement on data management adopted by government institutions in Indonesia is a prospective spatial data mining opportunity. The base map is a geocoding instrument for mining such data, which is one of the essences of administrative boundaries base map in the NSDI.

5.3 USING RS IMAGES AND PAD FOR MONITORING DEFORESTATION OF TROPICAL PEATLAND: CASE STUDY OF SEBUBUS FOREST, WEST KALIMANTAN, INDONESIA.

5.4 Relationship between RT area, waterways, and land cover.

6.1.1 Waterways as accessibility means to the forest

AWs play very important roles on tropical peatland sustainability. Its existence contributes hugely to the destabilization of the tropical peatland's water table (Osaki & Tsuji, 2016). They drain tropical peat dome (Susan E Page et al., 2002) and change the nature of water flows which basically, owing to the convex character of tropical peat domes, flows in various directions as radial, widely spreadsheet flow rather than channel flow (H. Ritzema et al., 2014). In fact, most of tropical peatland exploitation usually begins with the construction of any types of AWs. They are constructed in the tropical peatland to make the soil suitable for agriculture activities (Cooper et al., 2014; Evers et al., 2017; S.E. Page & Baird, 2016; Rawlins & Morris, 2010); for transporting forest products (H. Ritzema et al., 2014; Suryadiputra et al., 2005); and becomes complementary structure in the road construction, in which their residual soil is usually used for elevating the road construction.

Thus, AWs can be reference objects to link tropical peatland deforestation with communities surround the ecosystem. In this study, the root of deforestation in tropical peat forest is explained by linking deforested area with surrounding RTs connected by Aws. For example, various social attributes of several RTs are used to explain a deforested area directly accessible through AWs. The attributes can be the demographic datasets, economic datasets, etc.

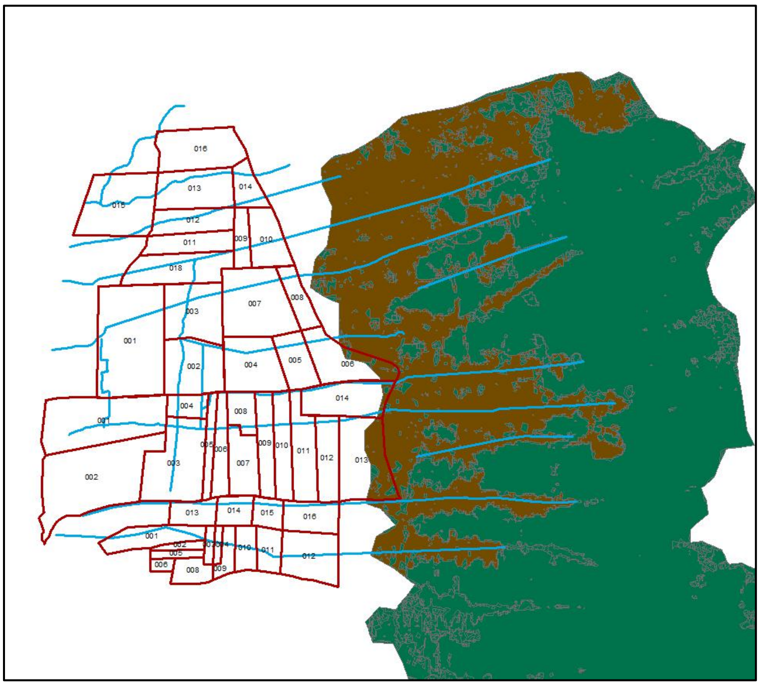

Figure 28: waterlines connect communities with Sebubus Forest

From above map, it can be seen that AWs connect local communities to the deforested area (brown in color). Every waterline is a channel to reach forest area. They give access for people to exploit the forest's resources. People who live nearer or connected directly to the waterlines are expected to have larger opportunity to exploit them. As the Tobler's first law of geography stated, everything is related to everything else, but the near things more related than distant things. Therefore, scrutinizing proximate communities is important to understand thoroughly deforestation in Sebubus forest.

6.1.2 Scrutinizing the people

As previously discussed, using current existing base map is not enough to scrutinize proximate communities in a scale such as of Sebubus Forest. Figure below shows why using new developed base map is required. Not to fully replace existing ones, rather as complementary tool for analysis.

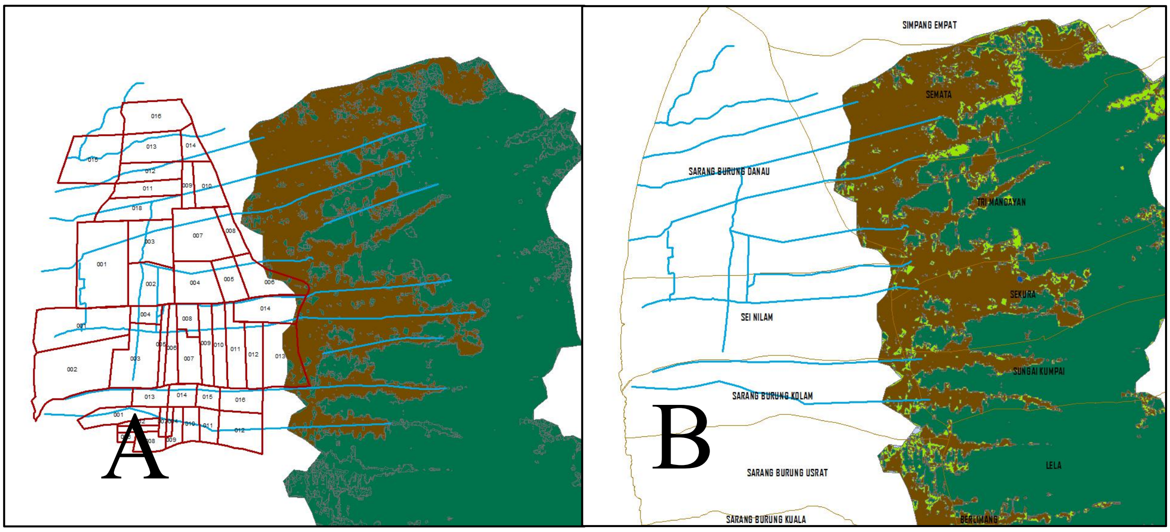

Figure 29: Analysis using different level of BM / RT (A) and Village (B)

Using RT as unit of analysis, communities are segmented into smaller fractions as can be depicted from above figure (A). Therefore, people who live nearest to the forest and those who distant can be detected. Meanwhile, using village base map (B) whole communities in a village is viewed as one unity. The nearest and the distant cannot be differentiated in such case.

5.5 Monitoring deforestation in the Sebubus Forest

As discussed on chapter 4.1, Sebubus Forest has experienced unprecedented occupation sometime between 2005 until 2009 as detected by RS analysis. Before 2005, the forest was relatively well maintained except in several parts around its boundaries. From image process it can be classified that around 80% from total 14.501 ha forest area was still covered by forest in 1995. While shrub, which comprised of around 13% of the area, mostly occupied its western boundary and edge of its southern part. It is likely that local communities did some agricultural activities in the peat soil as lands for livelihood were getting scarce for people of Jawai Sub District and Tekarang Sub District. Jawai Sub District in particular has higher density with limited land for developing its agriculture.

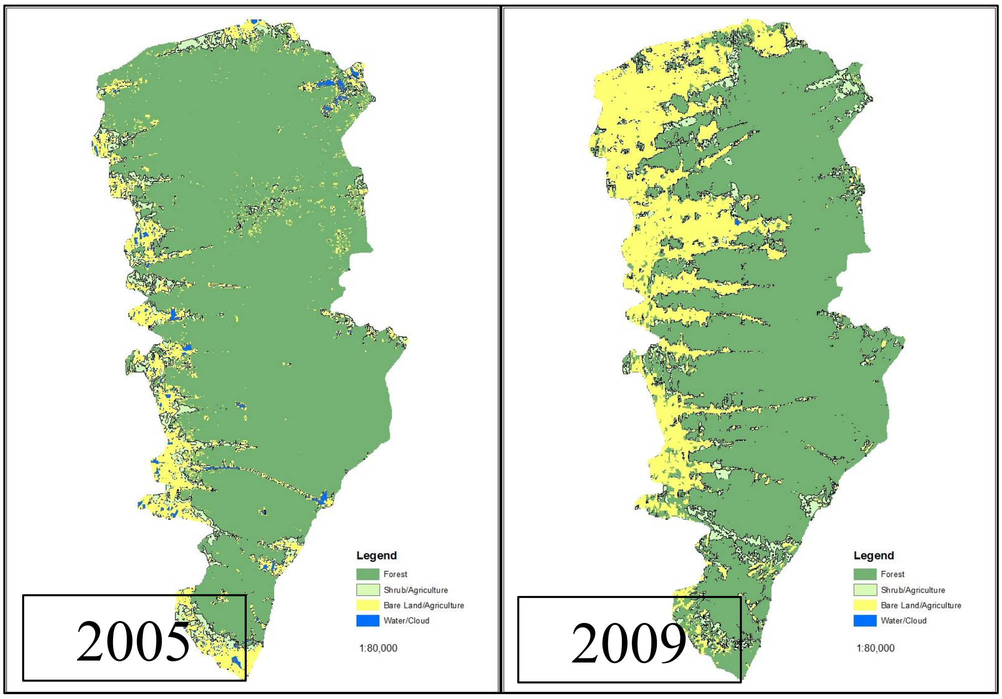

Figure 30: radical landcover change in Sebubus Forest between 2005 until 2009

It is hard to find appropriate administrative data for the year 1995 until 2010, because during that time Sambas Regency experienced severe social riot in which horizontal clash between different ethnic group caused tens of thousands of people being displaced and killed. Government activities were not normally run during the years.

RS images shows that by 2005, some activities began to infiltrate into the forest slowly. By the year 2009, huge deforestation detected on the northern edge of the forest. During that period, bare land increased from 179 hectares in 2005 became 3.267 hectares. That size constituted 22.53 percent of the total forest size. That significant increase was mostly related to 3 villages in Jawai Sub District named Sarang Burung Danau, Sei Nilam, and Sarang Burung Kolam.

In general, the population in Sebubus forest spread around in different pattern. First type of pattern is found in Desa Simpang Empat and Semata. Population in this cluster consisted many RTs with small population for each RT. The shape is like a hat on the head of the forest. The second pattern is high dense population in Tangaran and Sekura in which RTs with high density clustered. The third is RTs dispersed vertically from north to south with some parts horizontally line up toward the forest. The fourth is RTs disperse evenly and line up towards the forest from the West. The last is population living in RTs and Villages in Kecamatan (Sub District) Jawai.

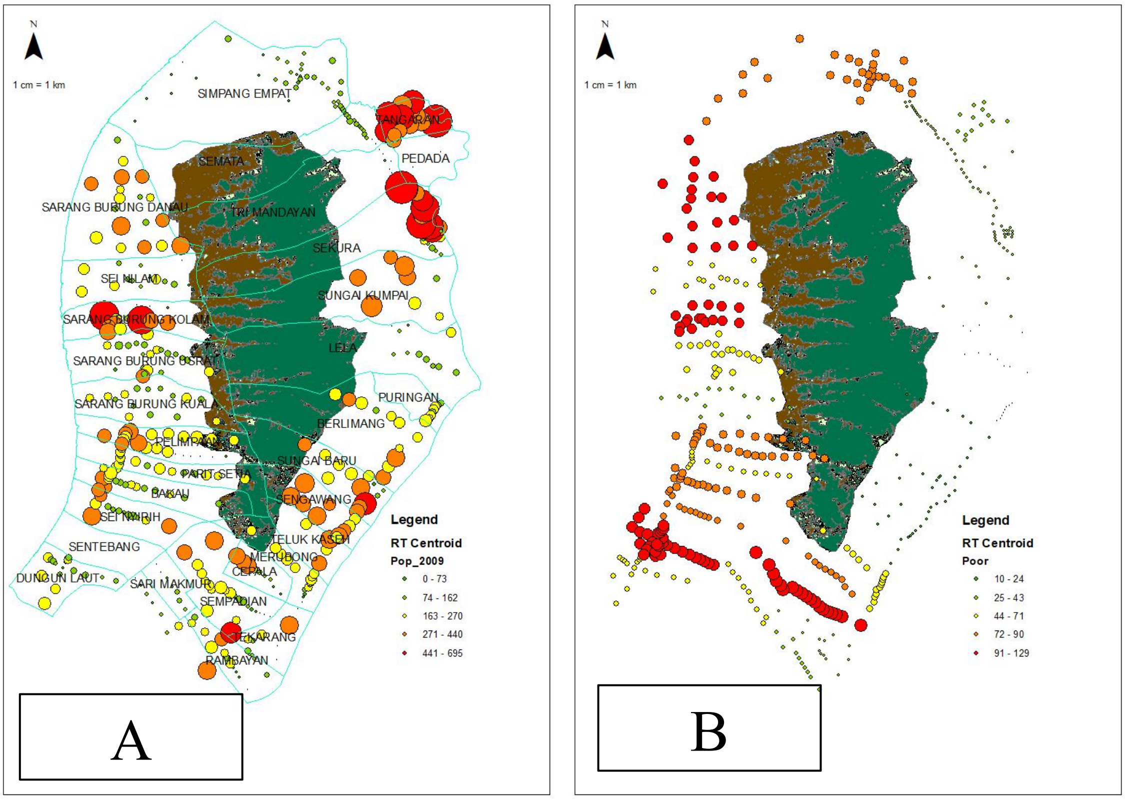

Figure 31: analyzing the population pattern using RT BM's centroid

Data source: TNP2K

In simple scrutiny, it can be seen that the pattern has something to do with the deforestation. Population in pattern four seems to have highest proximity to the deforested area. The lineup pattern indicates the residential area are growing towards the forest. This should have been known and given enough attention by authority to protect the forest.

On the other hand, based on the demographic data, number of poverty rates was higher in some villages where high deforestation happened. Map (B) shows that RTs with high poverty are nearer to the deforestation hot spot.

Poverty seems to have very strong relationship to the deforestation of Sebubus forest. Villages with poorest population are apparently located nearest to the area where large bare lands were detected in the forest. For example, Sarang Burung Danau is a village with high number of poor populations based on data from National Poverty Alleviation Eradication Committee. Population of the village is the most proximate to the deforested area based on RTs distribution.

Meanwhile, bringing the AWs into maps makes everything even clearer. Maps below depicts somehow poor population were living along the waterways penetrating to the forest with deforested area.

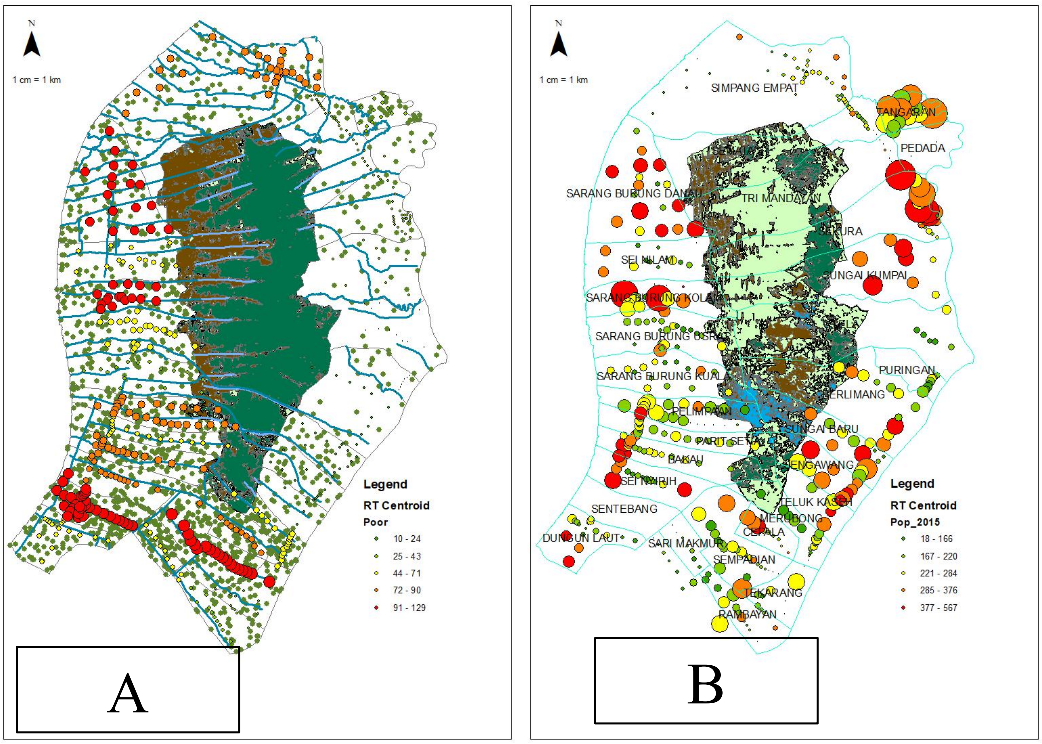

Figure 32: poverty, artificial ways, and landcover change

In village aggregate, in line with the poverty, some variables from demographic data also show the relationship between poverty and deforestation. Households depend on biomass as main energy for cooking around Sebubus Forest indicated high degree of spatial relationship. Villages with high rate of biomass dependent families were located in vicinity of deforestation. The other variable is number of households without access to clean water which is the distribution almost similar to the previous variable.

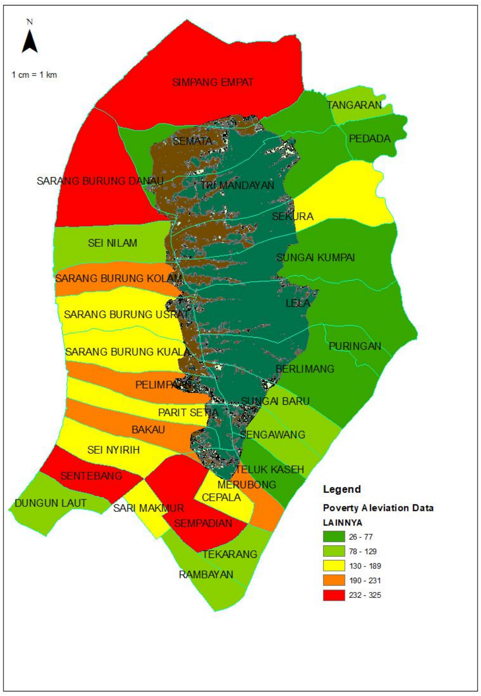

Figure 33: households dependent to biomass and deforestation

Meanwhile, the relationship of deforestation with land tax quite tricky. Land tax registration and payment is one of obligation for those who own land in Indonesia. The tax must be paid each year. However, it is not uncommon people pay their land tax multiple years at once. Data from Local Government of Sambas who govern the matter shows that few only people who register their land in Kecamatan Jawai which comprises of Desa Sarang Burung Danau, Desa Sei Nilam, Desa Sarang Burung Kolam, Desa Sarang Burung Kuala, Desa Pelimpaan, Desa Parit Setia, Desa Bakau, Desa Sei

Nyirih, Desa Sentebang and Desa Dungun laut. until 2011 in which sudden explosion of registration happened. There is no explanation why people did not register their land and sudden rush of registration happened.

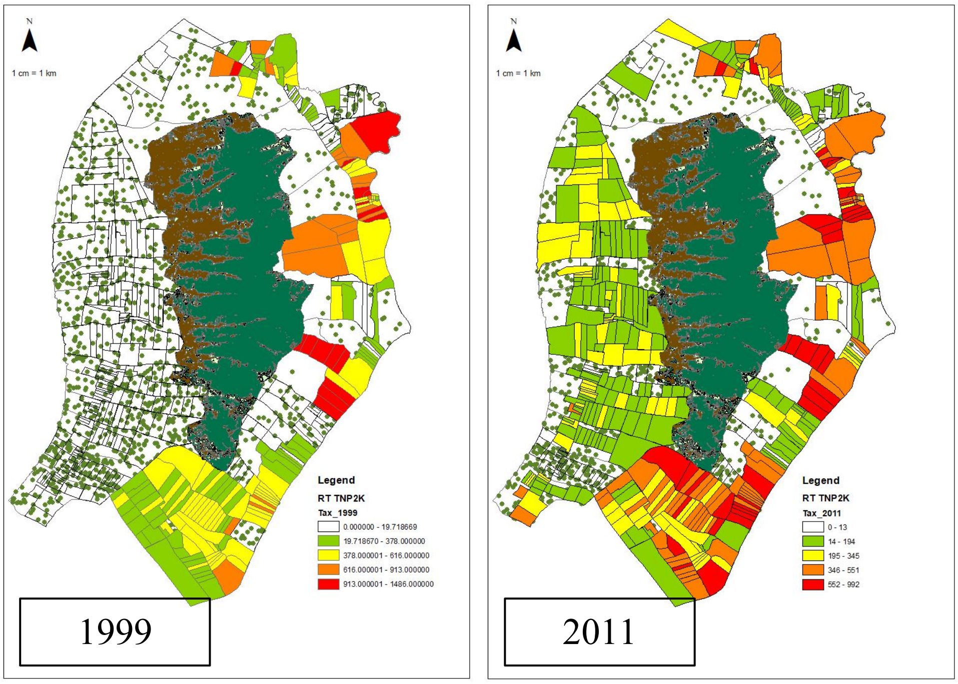

Figure 34: population density and tax registration visualized in RT BM

In order to focus on what is really happened, firstly, population on those connected area was analyzed by excluding others. There were 54 RTs on that area in which the population was expected 10.744 in 2009, 10.074 in 2010, 12.061 in 2011 and 14.172 in 2015. That constitute -6 percent, 20 percent and 18 percent growth respectively, which is 10 percent on average per year. Gravity of the population was located in Desa Sarang Burung Danau where RTs with big population found on the border of the forest. That situation seems coincidental with the massive deforestation in the forest area near the village during the period of 2005 until 2009.

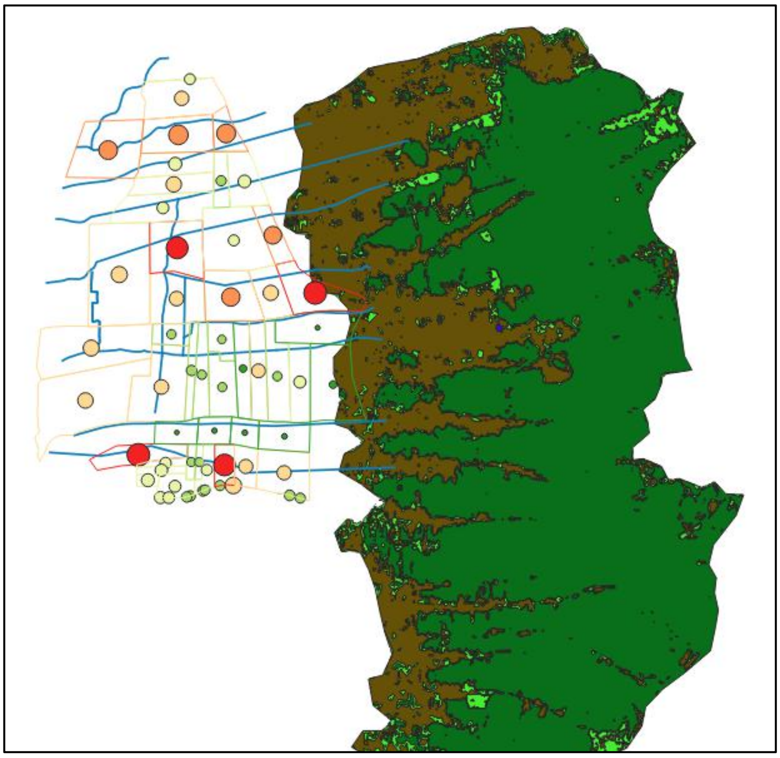

Figure 35: focusing on the deforestation hotspot area

Population in this area is spreading almost all over the area between the coastal line in the west with Sebubus forest in the east. RTs with big population are located just near the border of the forest. With high rate of poverty amongst the population, it is should have known that the communities are the main threat to the forest. Administrative data shows that population in the villages are very reliance to the biomass as their cooking energy and the forest is certainly their source.

6. DISCUSSION

6.1 Integrative monitoring approach and the systematic understanding of tropical peatland deforestation

RS analysis certainly gives policy makers and conservationists advantages on monitoring environmental resources. For tropical peatland monitoring, the advantages have more value since naturally tropical peatland forests area hardly accessible for ground observation. Using the advancement of the technology in this field, tropical peatland monitoring not only becomes easier but also cheaper. Yet the techniques may not really accessible to many government officials who should be familiar with them. Complicated frameworks and rigid technical procedures for example, makes the technology looked not interesting.

In this study, RS techniques proposed are made as simple as possible so that everybody can easily replicate it. Landsat images selection as presented on chapter 4.1 for example, can be done on reliance to visual capability. Meanwhile GEOBIA technique discussed on Chapter 4.2 is designed to maximize existing local knowledge as basis of executing stages of the procedure.

On the application level, case study in Sebubus forest gives very important lessons to help systematically understand the mechanism of deforestation of tropial peatland. . Based on local government official records, the forest is still in its normal condition. However, the time series Landsat images analysis show that the forest has been encroached extensively. The analysis is able to not only clarify the current condition of the valuable natural resources but also presents the stages of the events and finds critical moments when the deforestation began.

On the other hand, the applications of Object-Based Image Analysis (OBIA) in RS studies of wetlands/peatlands have been growing over recent decades. It has been used for wide range of purpose from detection and delineation of wetland/peatland bodies to comprehensive analyses of within-wetland cover types and their change (Dronova, 2015). OBIA methods were driven by the need to more accurately map multi-scaled Earth features with high-spatial-resolution imagery (HSRI) such as tree, the building, and the field (Blaschke, 2015).

Google Earth, released in 2005, is a satellite imagery-based mapping software which have been being used for wide range fields. Despite not always available to every required place, it has a lot of high-resolution data for many areas on earth. The resolution of the images can be less than 1 meter which makes it a valuable source for landscape monitoring.

Moreover, the free software also has multi-temporal capability, which is another advantage to monitor natural resources. However, it has also some limitations. One of them is that the pixel-based analysis may hardly be conducted using GEHRI as data because it may not be possible to obtain the original multispectral band data. That means the actual pixel numbers or the brightness/reflectance values can be get and hence image classification using unsupervised or supervised techniques cannot be carried out (Malarvizhi, Kumar, & Porchelvan, 2016).

In fact, HSRI is not really suitable for pixel-based analysis. In RS or image analysis, it is known that as long as pixel sizes remained typically coarser than, or at the best, similar in size to the objects of interest, emphasis was placed on per-pixel analysis or even sub-pixel analysis for this conversion, but with increasing spatial resolutions alternative paths have been followed, aimed at deriving objects that are made up of several pixels (Blaschke, 2015). In geographical domain, this technique is called GEOBIA (GEOBIA). It is a growing RS technique in RS analysis (Blaschke et al., 2014). In the process, instead of uses individual pixels, this technique analyses objects from segmentation. It means objects are classified using color, shape, size, texture, and context. Therefore, the GEOBIA can make full use of the spectral, texture, geometry and other characteristics of GEHRI, which is supposed to compensate the limitation of poor spectral characteristics of the images (Hu et al., 2013).

In this study, the technique is used to monitor the development of AW in tropical peatlands. In the case study area, the stages of AWs development are clarified using the advantage of the technology. GEOBIA technique in this study, as aforementioned, is simplified to be executable by non-expert officials. The simplification makes it different than other previous research.

There are some previous researches applying GEOBIA in the wetland/peatland area. A review by (Dronova, 2015) presents a synthesis of 73 studies regarding wetland/peatland that applied OBIA to different types of RS data, spatial scale and research objectives. She found that based on their objectives the researches could be grouped into five groups:

1. Detection & delineation: studies detecting the presence and/or delineating their boundaries in landscapes with significant proportion of non-wetland/peatland natural and anthropogenic land cover
2. Typological classification of delineated wetland units: assignment of mapped wetland bodies into hydrological, geomorphological and ecological categories without detailed mapping of within-wetland/peatland cover;
3. Classification of within-wetland cover types and/or vegetation: mapping within-wetland surface composition and vegetation types, sometimes targeting specific classes such as invasive plant species

4. Analysis of wetland/peatland's change over a particular period of time
5. Analysis of within-wetland biophysical and ecological properties using OBIA outcomes for subsequent ecological study: wildlife habitat analyses, spatial modelling of ecosystem properties such as carbon stocks, net primary productivity, wetland/peatland geomorphology and vegetation structure, and analyses of disturbance.

In regards to those grouping, this study basically can be included into the fifth group. However, Key differences to previous ones are on the technique level. While previous researches mostly merely focus on image characteristics, this research goes into ground level to develop a knowledge foundation before going into image semantic analysis. This study also different in term of its use on monitoring AW as the focus, that is less studied previously.

At its most fundamental level, OBIA requires image segmentation, attribution, classification, and the ability to query and link individual objects (aka segments) in space and time (Blaschke, 2015). Segmentation is viewed as key factor for successful analysis. In previous researches reviewed by (Dronova, 2015), segmentation outputs are often controlled by parameters that constrain within-object spectral variation, or heterogeneity, as well as other method-specific criteria. To do so, specific application and data, which is usually expensive, is needed and at least intermediate RS skill is required. Meanwhile, GEHRI is free software and easily used, but images or series of images may come from different sensors. Therefore, characteristics of the images may vary depend on how the sensors interact with ground objects. Understanding the ground objects in this sense becomes important to understand the image semantics.

Currently, there are several software packages for GEOBIA, such as Erdas Objective, ENVI EX, IDRISI, etc. Better application to be used depends on many aspects. Skill, available resources, and study purposes determine which application is better choice. However, in this research, we prefer to maximize the use of GEP, not only for simplification but also to optimize the advantage of free popular applications. On the other hand, HSRI is the current easiest way to obtain RS data. This data can be obtained using a small drone or even simpler is, by using an open geospatial database available from the Internet such as of the GEHRI. Using HSRI, we can see details of many objects on the ground. Hence, the human visual capability can be used to conduct image analysis. As a human being, we are a very good image analyst. We can extract higher-level image features. As we know, the human visual cortex is an excellent image analysis apparatus, human visual perception model is a basic inspiration of many image analysis tools such as edge detector, or neural network (Khodaskar & Ladhake, 2015). Simply, combining human visual capabilities and existing ground knowledge to analyze GEHRI using GEOBIA approaches supposed to be a good option for monitoring AWs in tropical peatlands.

6.2 PAD as potential spatial big data.

Despite their problematic nature, PAD is a potential big spatial data sources that should not be neglected. PAD is a prospective data source for better understanding human-environment relationship. This is not special for Indonesia in which demand is increasing for research-based policymaking, but also to other countries. With the potency, it is valuable to governments to improve the quality of PAD to meeting up with research requirements. High quality PAD will ease the task of researchers and analysts and further will benefit the government and societies in general. In the nuance of that reasons, improvement on generating, linking, managing, and sharing PAD are necessary. Meanwhile, development of theoretical bases, both in the conceptual and framework levels for conducting spatial research using PAD is also important.

Usability of PAD for GIS based research and analysis in Indonesia has prospective future yet several challenges are there. Data quality is one of obvious challenges. The quality here means reliability and validity of the data. Public institutions are required to improve their data. Standardizing how the data generated can be one of viable options. One Map Policy and One Data Policy can be prospective policies for linking PAD geographically. However, Indonesia is still in the first stage in open data policy (Gunawan & Amalia, 2017). Some serious measures are required wide use and benefit. Some data have been well established.

Example of PAD that well established and widely used is Potensi Desa (Village Potency). This data are collected regularly by Indonesia Statistics. These databases contain large information and have been published in many libraries such as of Duke University (Duke University Libraries, n.d.). Tax data also very important and can be used to improve the timeliness, coverage, and quality of national accounts data while reducing costs and reporting burdens (Rivas & Crowley, 2018).

Improving data or record quality alone will not enough to enhance the usability. An enhancement of the appropriate base map for better analysis is as important as improving the data/record quality. As proposed in this study, RTBM can be included as part in the ISDI. Population census village sketch maps can be a data source for developing an RTBM. However, RT as the smallest administrative entities need to be mapped properly. It is also important to map them regularly following the changes of data aggregation in the administrative system. On the other hand, using RT as a base for data aggregation can help deidentifying individual records, which is important for protecting personal privacy in a data analysis, while reducing geographical bias in regards to its higher resolution of spatial unit of analysis. Since RT is the smallest administrative area in the country, using its area for integrating PAD gives advantages. Not only it can give a higher resolution but also can encompass other higher level of aggregation if it is required.

Finally, as presented in this study, using an administrative unit for integrating PAD can enhance the value of the PAD. Using smallest administrative unit, such as RT in Indonesia case, gives powerful insight into PAD. Yet more studies are required both in PAD and base maps as well.

6.3 Limitation of this study

Limitation of this study is that it is tested in one case study only, therefore, some modification is certainly needed for wider use in vast tropical peatland area. However, the core components and main ideas should remain applicable. For example, while the grand design of the integrative model should be applicable to nation wide, local knowledge for image semantic in the GEOBIA should be different based on localities. Size of canals for instance may vary in each island where the tropical peatland exists. It very much influenced by local culture.

For RTBM, names of the smallest administrative units may different despite using the same rule and concepts. Each regency may also regulate the administrative entities based on local wisdom. For example number of households and the total area may be regulated strictly in some local governments.

However, the good point about RTBM is that the data source (village sketch maps) are the product of uniformed process. The mapping of the sketch maps is always conducted with rigid procedure. The mappers are always trained and the guidelines are released prior the mapping. Therefore, the data source should be nation wide available and the procedure can be standardized as it is uniformly produced.

7. CONCLUSION

The importance of tropical peatland ecosystems to the environment and social-cultural life is increasingly understood. Some through attraction of scientists and researchers all around the world to the issues. Those scientists and researchers have been racing to the development of scientific formation in the field. However, those of several disastrous environmental events which have given hard lessons to make even stubborn politicians understood the importance. Bring the issue to the front and attract more effort for the conservation management improvement.

This study emphasized the importance of the tropical peatland deforestation monitoring as the core of the natural resource conservation management efforts. Monitoring deforestation and its social roots is one of key factors determining the success of tropical peat management in the future. There is, however, still very little comprehensive knowledge of the socio-economic, socio-cultural or socio-ecological aspects of tropical peatland ecosystems (Page, Rieley, & Wüst, 2006). Therefore, for such purpose, new methods capitalizing contemporary approaches and techniques such as of RS application which is complemented with big social data are important.

As a fundamental core of framework and methods developed in this study, two biophysical elements of the tropical peatland deforestation variables are emphasized. Those are the landcover change and the existence of AWs. Land cover change reflect the loss of biodiversity, cessation of peat accumulation cycle, and potential threat to wild fire events. Meanwhile, existence of AWs reflects the decrease of water table, subsidence occurrence, and hydrological disturbance. On the other hand, human activities and social cultural variables are studied using PAD as a potential big data source for spatial based research and analysis.

There are several reasons why developing integrative methods for monitoring tropical peat forests is required. One of the reasons is that deforestation of tropical peat forest generally happened due to pressures from human activities inside or around the ecosystems (Brun et al., 2015). Therefore, seeing the deforestation merely on the ecological aspects may not much help to halt the increase. For example, RS can give clear picture of the loss of tropical peat canopy. But it hardly explains why do people cut the trees. On the other hand, detecting the loss of the forest itself may not really help, since it has happened. Meanwhile, seeing it from merely social aspects also hardly giving a clear picture of what really happened to the forest. For example, to draw precise lines and the stages based of deforestation on temporal sequence is hardly achieved unless using RS data, particularly in a large area.

The other reason is related to the importance of the reciprocal relationship between the communities and the tropical peatland. While people may the main actor of the tropical peatland deforestation, they can and always certainly be impacted with the adverse consequences. In this case, monitoring the adverse impact of the deforestation of tropical peatland is another benefit of the integrative approach.

The application of developed framework and method through case study in Sebubus forest shows that it is applicable. The use of PAD is challenging. For example, some data for some areas are missing. This will be future challenges for those in two different domains. For policy makers there is a need to improving PAD management so that the use of PAD can be optimized for the benefits of society and the government itself. On the other side, scientists and academician are required to giving more attention on the use of the potential big spatial data from daily government affairs.

Furthermore, regarding the case study in Sebubus forest, the protected forest should have not experienced so much extreme deforestation. The degree of the destruction, as clarified through the RS analysis is so massive that it is seemingly irreversible. The analysis also found the critical period of the beginning of massive infiltration to the forest. Meanwhile, the PAD analyses are able to clarify the social factors behind the deforestation. Deforestation certainly has something to do with the poverty rate in some villages. Patterns of population distribution indicates some factors contributing to the community's infiltration to the protected forest area.

In addition, despite its status as protected forest, Sebubus forest has been experiencing massive open exploitation. This finding indicates a need to reinforce regulation on protected forest. Results of this study also suggest that there is a need on a new approach of tropical peatland preservation and management. Human pressures threat the ecosystem in an unprecedented speed. It is so vulnerable that the huge ecosystem may loss in one month of even one day. However, it is often, recognizing the vulnerability is far from simple, and understanding its cause is even harder (Yan & Galloway, 2017). Simple approach of monitoring in which non-specialist researcher can do it has been presented in this study. The applicability has been tested, but the real benefit is when the tropical peatland has been saved.

In summary, this dissertation presents an original works for an integrative tropical peatland monitoring in which biophysical aspects and human factors behind the deforestation are assessed through RS images and PAD analysis. While, RS analysis successfully clarify the states and stages of the deforestation, PAD are used for retrieving the involvements of communities. The integrative approach is a systematic understanding of the deforestation in the tropical peatland in wich AW found playing a key role in the progress. It also successfully detected the AW in place and trace out the possible social entities involved in the development. Key components of the integrative approach are the GEOBIA and RTBM as a geocoding tool. Limitation of this study is that it is tested in one case study only, therefore, some modification is certainly needed for wider use in vast tropical peatland area. However, the core components and main ideas should remain applicable. Finally, it can be concluded that the framework and methods can enrich existing literature as well as contribute to the improvement of current tropical peatland conservation in Indonesia. Practically it can used to stop new projects of AW development in the tropical forest. More over, the procedure of RTBM Development could be a model for developing a new layer of Indonesia NSDI. While, the data sources of this thesis is prevalent and accessible for local governments in Indonesia, it can be used to enhance policy recommendation for specific target of poor RT for effective and efficient social development policy.

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