LANDCOVER PATTERN ANALYSIS OF TROPICAL PEAT SWAMP LANDS IN SOUTHEAST ASIA

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ABSTRACT:

Tropical peat swamp lands in the Southeast Asia which store tremendous large amount of carbon in their peat layer and abundant biodiversity are now endangered by human activities such as deforestation, forest fires, land development and urbanization. To earlier start a better environmental policy for conservation of nature of the tropical peat swamp area is one of the preferential global issues. This study aimed at 1) clarifying the state of the tropical peat swamp area in terms of the areas of each land cover categories, and 2) locating the regions where environment have been severely damaged or lands have been extensively developed.

  Some digital environmental data such as GeoCover, GeoCover LC, SRTM, digital soil maps and so on were analyzed to estimate land cover maps of fine scale around 2000 region by region. As a result of this analysis, following characteristic on the land cover pattern in the Southeast Asia are clarified.

(1) The total area of the tropical peat swamp lands in the Southeast Asia are estimated to be 25,119,825ha. 43.1% of them is in Papua, Indonesia, 22.5% is in Sumatra, 22% is in Borneo, Indonesia. Others are in Peninsular, Malaysia, Thailand, and Borneo, Malaysia.

(2) 15,181,388 ha of the tropical peat swamp area in the Southeast Asia is covered with Forest. 3,346,831 ha is with the Swamp forest mixed with bush. 4,866,988 ha is with the Bush, Secondary forest including Industrial forest. 822,756 ha is with Bare land and Buildup area. 467,244 ha is with Agricultural lands such as mixed garden, oil palm plantation and developed lands. 434,619ha is Grass land. These estimates mean that 73.7% of the tropical peat swamp area is remaining as densely vegetated land and the rest of 26.3% of area has been already developed for human activities such as industrial forest, urban and buildup area or agricultural lands. Moreover, 6.9% of the tropical peat swamp area in the Southeast Asia has non-vegetation or poor vegetation; that 93.1% of the tropical peat swamp land is still covered with rather vegetation.

(3) Using with the SRTM90 data, the acreages of land covers in TPSA distributed in the Southeast Asia up to 100m a.s.l were computed. Consequently, almost land covers in the tropical peat swamp area expand in lower lands than 50m a.s.l. in every region, and 6.87 million ha in the TPSA in the Southeast Asia is occupied by developed lands.

1. INTRODUCTION

The importance and functions of tropical peat swamp lands on the global carbon cycles and ecosystems has been clarified through many scientific research works such as Archard(2002), Page et al.(2002), Hooiger(2006) ,Myers et al.(2000), Wösten et al. (2008) and so on. Archard(2002) pointed out that tropical peat swamp lands were rapidly decreasing in area. Page(2002) estimated the amount of CO_2 emission after huge forest fires in tropical peat swamp lands in Kalimantan island in 1997. Myers et al.(2000) warned that hot spots of biodiversity in tropical forest in the Southeast Asia had been endangered by anthropologic activities such as land development or loggings. Hooiger(2006) emphasized that the wise use of tropical peat swamp lands is urgent issue of human kinds. Wösten et al. (2008) recommended that submerge condition of tropical peat swamp lands were very preferable for conservation of regional ecosystems and reduction of CO_2 gas release from peat layer to the atmosphere.

Ishida et al.(2008) measured the CO_2 gas fluxes from the ground surfaces of several land cover such as natural tropical peat swamp forest; annually submerged lands, the secondary forests; seasonally submerged or annually dried up, developed agricultural lands such as oil palm plantations and sand dunes in the tropical peat swamp lands area of Narathiwat province in southern part of Thailand. Then, they found that the CO_2 gas flux from the ground surface were strongly depending on water contents of peat layer and land cover types. Through these findings, in order to take the function of carbon budgets in tropical peat swamp lands on the global carbon cycle into accounts and to conserve their unique ecosystems as contributing to environmental planning, land cover pattern in tropical peat swamp lands must be studied in detail and mapped in as fine scale as possible.

The objectives of this study are to estimate the tropical peat swamp area and to analyze their distribution pattern of land cover in Southeast Asia using satellite remotely sensed images. Moreover, we investigate the affiliation of such pattern as considering land elevation in that area, in order to set up the

wise use of tropical peat swamp area, particularly in Southeast Asia. In this paper, GeoCover 2000 data and GeoCover LC 2000 data which were produced from Landsat TM and ETM+ data observed around 2000 were mainly analyzed. They possess consistent land cover information in tropical peat swamp areas over the Southeast Asia; including the southern part of Malay Peninsula, Sumatra island, Kalimantan (Borneo) island and New Guinea island. Almost of tropical peat swamp area in the Southeast Asia extends to these islands (Hooijer 2006) .

2. DATA AND METHODS

2.1 Satellite data

According to Polak(1975), the extent of the tropical peat swamp area in the Southeast Asia is from 5 degrees in north to 9 degrees in south of latitude and from 95 degrees in east to 142 degrees in longitude. In order to obtain land-cover distribution pattern in the tropical peat swamp areas in the Southeast Asia as exactly as possible, GeoCover 2000(GLCF http://glcf.umiacs.edu.edu/data/) and GeoCover LC 2000 (MDA Federal Inc.http: //www.mdafederal.com/geocover /geo coverortho/) datasets which were observed around 2000. GeoCover were mapped by using ortho-rectified Landsat Thematic Mapper(TM) and Enhanced Thematic Mapper (ETM+) Compressed Mosaics. Data sets of GeoCover LC were known as products from GeoCover; land cover classification results derived from GeoCover datasets. They have high spatial resolution of 28.5m by 28.5m on the ground.Following satellite data were used other than GeoCover datasets and GeoCover LC datasets. MODIS image data(https://lpdaac. usgs.gov/ content/view/sitemap/2), some digital soil maps of Indonesia (Bakosurtanal http://www.bakosurtanal.go.id/), and SRTM (Space shuttle Rader Topography Mission http://edc.usgs.gov /glis/hyper/guide/1_dgr_demfig/ states.html) data as a DEM data(digital elevation model data) were used. Moreover, Google earth views(Google earth http://earth.google.com/) of recent earth surface of interests were also used.

2.2.1 GeoCover 2000 and GeoCover LC 2000: GeoCover and GeoCover LC products are available in 3 periods; around 1990, 1995, 2000. In this study, the recently compiled GeoCover 2000 data sets and GeoCover LC 2000 were used, because they were latest. GeoCover 2000 can be obtained freely through the home page of Global Land Cover Facility (GLCF) (http://glcf.umd.edu). GeoCover LC 2000 data were land cover results from GeoCover 2000 products. They have been distributed by MDA Federal Inc. (http://www.mdafederal.com /geocover/geocoverlc). GeoCover is a collection of Landsat data that provides almost globally coverage, collected for three series: (1) the 1975 edition, with imagery collected from 1973 to 1989, (2) the 1990s edition, with imagery collected from 1989 to 1997, and (3) the 2000s edition, with imagery collected between 1999 and 2002. These scenes were acquired within around years of peak of greenness in that period (1975, 1990, and 2000). Their image data have three spectral bands: they are band 7 (mid-infrared range), band 4 (near-infrared range), and band 2 (visible green range). The GeoCover datasets is provided in a standard GeoTIFF format with UTM projection and using the World Geodetic System (WGS) 1984 as a datum. Detailed description of GeoCover data can be found at the web-site of NASA(http://zulu.ssc.nasa.gov/mrsid).

GeoCover LC data are land cover classification results from Landsat TM or ETM+ imagery identical to GeoCover data, and

they are distributed by MDA Federal Inc. Analysts of MDA Federal Inc. have independently analyzed and classified each scene using ERDAS IMAGINE for land cover mapping (http://www.mdafederal.com/..../gclcdataproduct/).The detailed algorithm of image classification for GeoCover LC data set from GeoCover data is referred in the web-site of MDA Federal Inc. Since these results of classification were validated by local specialists in each region, they are considered as most reliable and finest land cover data sets in global scale (Koelon, *et. al.*, 2000). The reason why we used two kinds of GeoCover product are mainly amounts of cost to purchase GeoCover LC data of the whole area of our interest and cloud covers in the images of GeoCover LC. Since it was hard for us to purchase all the GeoCover LC data for completely covering whole the area of tropical peat swamp lands expanding to the Southeast Asia with our limited research fund, we selected and purchased only 32 scenes of GeoCover LC 2000 data which were covering large fractions of tropical peat swamp lands in those scenes. The rest of scenes which were covering small fractions of tropical peat swamp lands in those scenes were not purchased, but downloaded from the web-site of GeoCover data of NASA(GLCF http://glcf.umiacs.umd.edu/data/). The total number of scenes of Landsat images for covering the whole area of the tropical peat swamp lands in the Southeast Asia is 118 scenes. The same algorithm for unsupervised land cover classification on these downloaded GeoCover data; ISO clustering were conducted and interpreted with 13 land cover categories. These 13 land covers are described later.

2.2.2 Moderate Resolution Imaging Spectroradiometer (MODIS) data: Some of Moderate Resolution Imaging Spectroradiometer (MODIS) data(http://modis. gsfc.nasa.gov/) were also used other than GeoCover LC and GeoCover data. These MODIS data compensated for blank areas such as "No data" including clouds, shadows, and noise in GeoCover LC and GeoCover data. The MODIS data observed on close days when Landsat images for GeoCover data were observed were used. The major purpose of using MODIS data in this study is to generate the cloudless image.

2.2.3 Shuttle Radar Topography Mission (SRTM) SRTM data:
  Information of land elevation are helpful to discriminate peat swamp lands in coast area from inland swamps. Digital Elevation Model(DEM) such as GTOPO30 or SRTM90(CGIAR-CSIS SRTM 90m DEM Digital Elevation Database URL: are available for this purpose. They can be downloaded from web-sites of USGS(http://edc.usgs.gov/ products/elevation/gtopo30/gtopo30.html) or NASA JPL(http:// www2.jpl.nasa.gov/srtm/). In this study, SRTM90 data, of which spatial resolution is 90m by 90m, were used (http://srtm.csi.cgiar.org/). In this study, the spatial analysis was determined using not only land-cover types derived from GeoCover (and MODIS) image set but also spatial analyzed by the shuttle radar topography mission (SRTM). Information of such land elevation is helpful to categorize peat swamp lands in coastal land and inland swamp area. These elevation data are also used to assist the delineating of peat soil area in Papua, while the soil map available is only the FAO soil map.

SRTM data are accessible for free download through the internet (e.g. via ftp://e0srp01u.ecs.nasa.gov and http://seam less.usgs.gov/). Because SRTM data produced a number of voids due to the lack of contrast in the radar image, a methodology based on spatial filtering was developed to correct this phenomenon (Jarvis et. al., 2004). The final seamless dataset with voids filled in is available at the website of

Consultative Group for International Agriculture Research Consortium for Spatial Information (CGIAR-CSI) via http://srtm.csi.cgiar.org/. SRTM data "final corrected" by CGIAR-CSI of which has spatial resolution 90m x 90m were used in this study.

2.2.4 Google Earth view: In addition to analyze land cover distribution, Google Earth views (Google Earth ver. 5, 2009) have been used in order to describe the recent earth surface of such area. While re-classifying land cover categories on the results of unsupervised classification of GeoCover data or MODIS data, visual interpretation of recent aero-photographs or high spatial resolution satellite images of interest area helps better identification of land cover types. Views of Google Earth(http://earth.google.co.jp/) were used in this study to confirm and decide land cover categories.

2.2.5 Soil data: In order to analyze land cover distribution pattern in the tropical peat swamp area in Southeast Asia, several datasets such as rasterized soil maps, satellite images, a digital elevation model and digital land cover maps were used in the analysis as follows. They are finer scale soil maps than FAO digital soil map(FAO http://daac.ornl.gov/source_ documents/faosoilmaps.html). The information of peat soil area in Southeast Asia was obtained from datasets of soil map of FAO (2005) that has covered Europe, Africa, Asia and Australasia, whereas were compiled on the Miller oblate stereographic projection, soil map of Center for Soil and Agro-climate Research of Indonesia (1991), Directorate of National Mapping of Malaysia and Land Development Department of Thailand.

First we synchronized the soil datasets with the same definition of "peat soil", whereas by FAO classification such soil type was called Histosols (folists, fibrists, hemists, and saprists), by Soil Research Institute of Indonesia they are called tropofibrists, tropohemists and tropofibrists, with local language "gambut" (peat). Malaysia and Thailand soil classification systems were classified the peat soil into organic soil and peat/muck soils, respectively. Furthermore, each data was rectified and re-sampled in the same system as GeoCover, that are delivered in a Universal Transverse Mercator (UTM) projection on World Geodetic System (WGS) 1984. Then, the areas where the peat soil are distributed in Southeast Asia, were digitized by ArcGIS9.1 with RMS error less than 0.01 min. In digitizing, that process was also considered the elevation data in delineate boundary line of peat soil in that area, especially for Papua island (Indonesia and Papua New Guinea).

4. DATA PROCESSING

4.1 Land-cover categories for analysis

It is most important to firstly determine proper and consistent land cover categories in a land cover classification scheme using with satellite remotely sensed images, in order to estimate valid and reliable land cover maps. The land cover categories used in GeoCover LC products have thirteen categories including No Data and Clouds. They are (1)Deciduous Forest, (2)Evergreen Forest, (3)Scrub/Shrub, (4)Grassland, (5)Barren/Sparse Vegetation, (6)Urban/Built Up, (7)Agriculture-Other, (8)Agriculture-Rice, (9)Wetlands-Herbaceous, (10)Wetlands-Mangrove, (11)Water, (12) Ice/Snow,(13)NoData/Clouds (http://glcf.umiacs.umd.edu /portal/geocover/earthsat/geocover_lc.pdf). As taking essential

land cover categories in tropical regions of our interest into accounts, these thirteen land cover categories are redundant. We re-classed them into following eight categories; (1)Forest, (2)Swamp forest & mixed bush, (3)Bush and Shrub, (4)Grassland, (5)Bareland, (including built up area), (6)Mix garden, oil palm plantation in developed area, (7)Water, (8)Shadow, water and shaded by topographic effect of vegetation, and No data (cloud).

As taking essential land-cover categories in tropical regions of our interest research location, the 13 categories of GeoCover LC product looks redundant and inaccurate. Since then, we reclassified them into 8 categories, as follows: (1) Forest, (2) Swamp forest & mixed with bush, (3) Bush/shrub, (4) Grassland, (5) Bare land, include settlement, (6) Mixed garden, developed area e.g. oil palm plantation, (7) Water, and (8) No data, include cloud, shadow and shaded by topographic effect. However, finally we have omitted the "no data" class (cloud, shadow) through replaced by composite 8-days MODIS data. Table 2. shows the re-classified way from GeoCover LC to new land- cover categories.

4.2 Classification methods

4.2.1 Data preparation: In preprocessing stage, first the images of GeoCover, GeoCover LC, MODIS and SRTM data were imported into the imagine format (*.img) in ERDAS Imagine software. Every image was geo-referenced and then re-projected into the geographic projection and WGS-84 datum, using a first-order polynomial nearest-neighbor transformation. The rectification process has resulted in an smaller overall RMS error than 2-3 pixels.

4.2.2 Classification Method using GeoCover data: Since GeoCover imagery is the primary dataset of this study to obtain land cover maps other than GeoCover LC data, land-cover classification was conducted on every GeoCover image for the further analysis. Unsupervised classification with ISODATA clustering algorithm was used for land cover classification in which twenty classes was set as the primary land cover categories for ISODATA clustering. Then, outcomes of clustering were interpreted into land cover categories and reclassified into seven categories as referring the adjacent images of GeoCover LC data . The final land cover categories were same categories with GeoCover LC dataset. Moreover, this procedure of data processing was applied not only to GeoCover dataset, but also to MODIS data which were used to fill up the areas of "No data" in GeoCover LC dataset and land cover maps derived from GeoCover datasets. **Figure 1** shows the resulting landcover map of the tropical peat swamp lands in this study.

4.3 Classification accuracy assessment

Classification accuracy was briefly assessed in the same image of Landsat TM data as visually comparing classification result from GeoCover data with Geocover LC data. Classification results of GeoCover data showed almost the same land cover pattern with GeoCover LC data. These comparisons imply that the classification algorithm for GeoCover data in this analysis produces almost consistent results with GeoCover LC data. Land-cover have classified into 8 classes by ISODATA clustering process. As for classification accuracy of clustering and interpretation results were validated comparing them with GeoCover LC data of one of the same scene in Indonesia. The accuracy result showed that the overall accuracy is 87.8% and

the Kappa coefficient is 0.83, respectively. They are fairly good classification accuracy. Consequently, the classification results from GeoCover data are almost available for this research since the accuracy of classification results are considered to have consistent reliability on land cover classification of the GeoCover LC data.

4.4 Resulting the extent of the tropical peat swamp area and land covers in the Southeast Asia

Table 1 shows the final results of land cover classification with seven land cover categories defined in advance. It shows the land cover distribution in the tropical peat swamp area in the Southeast Asia. It shows the area of each land cover categories region by region. Kalimantan island has the largest area of the tropical peat swamp lands. Papua has the second largest area of the tropical peat swamp lands. The acreage of each land cover category in the Southeast Asia is shown at the bottom line of **Table 1**. The total area of the tropical peat swamp lands are 25,119,825ha; 1,030,781.25 ha(4.1%) in Peninsular, Malaysia, 56,475 ha(0.2%) in Thailand, 5,519,781.25 ha(22.5%) in Borneo, Indonesia, 1,754,031.25 ha(7.0%) in Borneo, Malaysia, 10,790,950 ha(43.1%) in Papua, Indonesia, 329,712.5 ha(1.3%) in Papua, New Guinea, and 5,638,093.75 ha(22.5%), Sumatra.

In other words, this distribution means that Malay Peninsula has only 4.3% of the tropical peat swamp area, and Sumatra island has 22.5%, Borneo island has 29%, and Papua island has 44.4%. And, comparing them country by country, the tropical peat swamp area in Thailand is only 0.2%, 11.1% in Malaysia, 87.6% in Indonesia, and 1.3% in Papua New Guinea. Almost 88% of the tropical peat swamp area in the Southeast Asia is expanding only in Indonesia.

Table 1 Acreage of Landcover classes in each region

Region	Forest	Swamp forest mix bush	Bush, sec forest, inds forest	Bare, builtup	Mix garden, oil palm, dev.	Grassland	SubTotal	Percent
Thailand	27,712.5	4,681.3	13,725.0	10,187.5	0.0	168.8	56,475.0	0.2%
P.Malaysia	368,468.8	190,475.0	273,587.5	129,943.8	32,837.5	35,468.8	1,030,781.3	4.1%
Sumatra	3,581,468.8	375,450.0	1,271,900.0	184,050.0	141,875.0	83,350.0	5,638,093.8	22.4%
Borneo-Indonesia	3,792,000.0	502,725.0	738,143.8	164,656.3	290,306.3	31,950.0	5,519,781.3	22.0%
Borneo-Malaysia	744,475.0	851,206.3	73,668.8	48,750.0	50.0	35,881.3	1,754,031.3	7.0%
Papua-Indonesia	6,455,537.5	1,372,075.0	2,446,268.8	274,381.3	2,175.0	240,512.5	10,790,950.0	43.0%
Papua New Guinea	211,725.0	50,218.8	49,693.8	10,787.5	0.0	7,287.5	329,712.5	1.3%
TOTAL SE Asia	15,181,387.5	3,346,831.3	4,866,987.5	822,756.3	467,243.8	434,618.8	25,119,825.0	100.0%
Percent	60.4%	13.3%	19.4%	3.3%	1.9%	1.7%		100.0%

From the view point of land cover distribution, the total acreage of Forest in the tropical peat swamp area in the Southeast Asia is 15,181,387.5 ha. That of the Swamp forest mixed with bush is 3,346,831.3 ha. That of Bush, Secondary forest including industrial forest is 4,866,987.5 ha. The area of Bare land and Buildup area is 822,756.3 ha. The area of agricultural lands such as mixed garden, oil palm plantation and developed lands is 467,243.8 ha. And the area of grass lands is 434,618.8ha. These figures mean 73.7% of the tropical peat swamp area, 18,528,218.8ha is remaining as densely vegetated land and the rest of 26.3% of area; 6,591,605.3ha has been already developed for industrial forest or secondary forest, urban and buildup area or agricultural lands. From another point of view of vegetation coverage; vegetated land or non-vegetated land, 93.1% of the tropical peat swamp area in the Southeast Asia is still covered with rather vegetation, while 6.9% of the area has no vegetation or poorer vegetation than forest. They are 23,395,206.3ha and 1,724,618.8ha, respectively.

5. DISCUSSION

5.1 Overall estimate of area of the tropical peat swamp area in the southeast Asia

The estimated acreage of the tropical peat swamp area in this research is almost same as that calculated by Hooijer (2006). In this research, it is 25,119,825ha, while it is 27.1 million hectares ha(Hooijer 2006). The difference between them resulted from mainly the difference of map scale and satellite images used in both study. Moreover, the difference of the content of organic content in the soil and regions; the island near Papua-Indonesia and inland swamps were ignored in our research(See Figure 2 in Hooijer(2006)). As overlaying digitized area of the tropical peat swamp area of FAO digital soil map onto soil maps we used, we can find the digitized boundaries of tropical peat swamp area of FAO soil map often go away from the boundaries of the tropical peat swamp area. We think we have a more accurate digital soil map than FAO soil map.

5.2 Regional spatial patterns of land covers in the tropical peat swamp area

Table 1 shows percentages of land cover categories, percentages and acreages of undeveloped land and developed land, and percentages and acreage of densely vegetated lands(Forest and swamp forest mixed with bush) and poorly non-vegetated lands(Bare lands, build-up lands, Mixed garden and Grassland) in eight regions. Spatial patterns of land cover; percentages of land cover categories are different region by region. In the peninsula Malaysia and Thailand, nearly 45% of tropical peat swamp land have been already developed and converted to industrial forests, build-up area or agricultural lands. While, in Borneo Malaysia, more than 90% of tropical peat swamp area remains as forest or swamp forest with bush. In other regions, 70% to 80% of tropical peat swamp area remains undeveloped.

However, in terms of acreage of developed land in each region, almost three million hectors of the tropical peat swamp lands has been developed in Papua, Indonesia and over one million hectors of the tropical peat swamp lands have been developed in Sumatra and Borneo, Indonesia, although their percentages of developed lands have been under 30%. On the other hand, only 24 thousands of the tropical peat swamp lands has been developed in Thailand. Moreover, focusing on green coverage in each region, almost 20% of the tropical peat swamp area of Thailand and Peninsula Malaysia are poorly vegetated or bare land. In other regions, they are under 10%. These figures point that Indonesia has developed the tropical peat swamp lands of nearly 6 million hectors, Malaysia has developed 630 thousands hectors of the tropical peat swamp area. Papua New Guinea has developed 68 thousands hectors and Thailand has developed 24 thousands hectors.

5.3 Land cover patterns and land elevation

Figure 2a,2b shows the accumulated acreage of developed lands in TPSA distributed in the Southeast Asia up to 100m of the surface elevation above sea level(hereafter, a.s.l.). The value of the surface elevation here is measures of SRTM90_ver.4 (CGIAR-CSIS SRTM 90m DEM Digital Elevation Database URL: http://srtm.csi.cgiar.org

6. CONCLUSION

Emission of immense amounts of CO_2 gases to the atmosphere from wetlands such as the tropical peat swamp area may play an important role on the global warming. Developed lands for agriculture or forestry in the tropical area are known as the serious sources of CO_2 emission because organic matter in the soil such as peat in TPSA easily decompose in succession of land drainage. So, it is necessary to globally estimate the total amounts of CO_2 emission from the dried developed lands in TPSA.

In this study, the total area of developed lands in TPSA in the Southeast Asia has been estimated by using several digital data source such as digital soil maps, digital elevation model and satellite remotely sensed imagery of high spatial resolution in order to calculate the CO_2 emission from developed lands in TPSA by taking accounts of emission rates of CO_2 from unit land. As results of this calculation, acreages of six land covers(excluding water surface and cloud/cloud shadows) in TPSA of the Southeast Asia were estimated with land elevations. Those estimates are follows.

(1)Using digital soil maps, the detailed extents of the tropical peat swamp area are digitized and finer land cover maps than other researches were also obtained.

(2)Acreages of land covers in the tropical peat swamp area in the southeast Asia were computed. They were as follows.

(a) The acreage of each land cover category in the Southeast Asia is computed. The total area of the tropical peat swamp lands are 25,119,825ha; 1,030,781.25 ha(4.1%) in Peninsular, Malaysia, 56,475 ha(0.2%) in Thailand, 5,519,781.25 ha(22.5%) in Borneo, Indonesia, 1,754,031.25 ha(7.0%) in Borneo, Malaysia, 10,790,950 ha(43.1%) in Papua, Indonesia, 329,712.5 ha(1.3%) in Papua, New Guinea, and 5,638,093.75 ha(22.5%), Sumatra.

(b) From the view point of land cover distribution, the total acreage of Forest in the tropical peat swamp area in the Southeast Asia is 15,181,387.5 ha. That of the Swamp forest mixed with bush is 3,346,831.3 ha. That of Bush, Secondary forest including industrial forest is 4,866,987.5 ha. The area of Bare land and Buildup area is 822,756.3 ha. The area of agricultural lands such as mixed garden, oil palm plantation and developed lands is 467,243.8 ha. And the area of grass lands is 434,618.8ha. These figures mean 73.7% of the tropical peat swamp area, 18,528,218.8ha is remaining as densely vegetated land and the rest of 26.3% of area; 6,591,605.3ha has been already developed for industrial forest or secondary forest, urban and buildup area or agricultural lands. From another point of view of vegetation coverage; vegetated land or non-vegetated land, 93.1% of the tropical peat swamp area in the Southeast Asia is still covered with rather vegetation, while 6.9% of the area has no vegetation or poorer vegetation than forest. They are 23,395,206.3ha and 1,724,618.8ha, respectively.

(c) Land cover patterns and land elevation

The accumulated acreages of developed lands in TPSA distributed in the Southeast Asia up to 100m of the surface elevation above sea level(hereafter, a.s.l.) were computed using with the SRTM90_ver.4 data(CGIAR-CSIS SRTM 90m DEM Digital Elevation Database URL: http://srtm.csi.cgiar. org/). The acreages of each land cover every 10m a.s.l. in TPSA in four regions were computed, and moreover, the acreages of disturbed lands, undisturbed lands, lands with poor green vegetation cover, and lands with rich green vegetation cover in four regions; Borneo, Papua, Sumatra and Malay Peninsula, respectively were computed. These estimates indicate that almost land covers in TPSA expand in lower lands than 50m

a.s.l. in every region. Undisturbed forest: forest and swamp forest, is the main land cover in each region. Developed lands, in another word, disturbed lands such as secondary forest, bare land, mixed garden and grassland lower than 50m a.s.l. occupy 6.87 million ha in the TPSA in the Southeast Asia. It is about 97% of total disturbed lands in TPSA of the Southeast Asia, which is estimated 7.08 million ha.

(4) The accumulated acreage of developed lands in TPSA in the whole regions; regions of Borneo, Papua, Sumatra and Malay Peninsula, were computed. In Papua, broader lands in TPSA have been developed than those in other regions. They were extending in almost lower than 30m a.s.l. Coverage areas and percentages of three land elevations of 10m, 20m and 30m a.s.l. were computed, respectively. These estimates indicate that lands of 2.31 million ha(32.6% of the total developed lands in TPSA of the Southeast Asia) could be submerged, when water would be logged in the water depth of 10m. Furthermore, lands of 4.79 million ha(68.7%) in the water depth of 20m and

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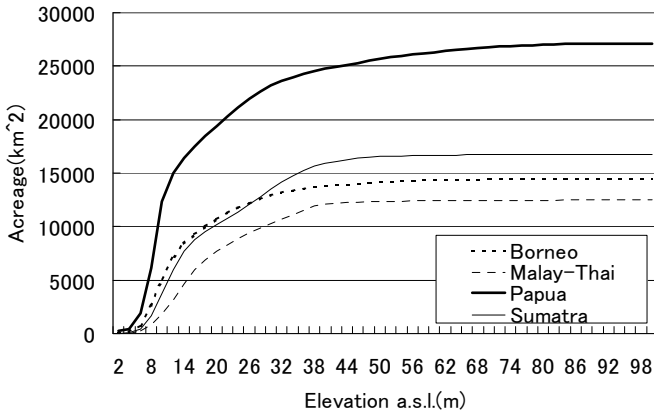Figure 1 Land cover in the Tropical Peat Soil Area
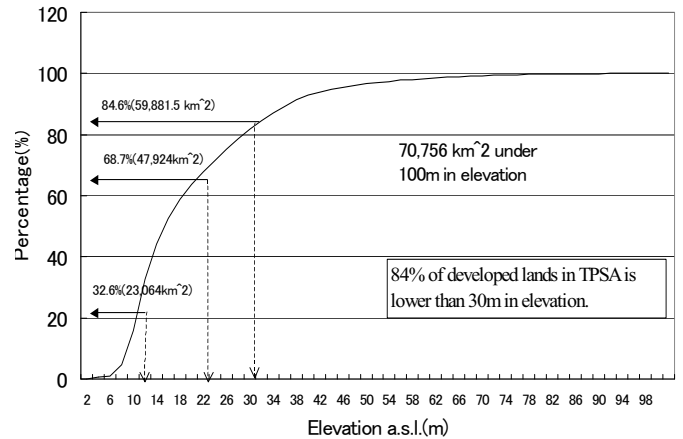

Figure 2a Acreage of accumulated developed land

Figure 2b Percentage of developed land in TPSA in Southeast Asia