# UNITAR's Operational Satellite Applications Programme

## Satellite Mapping of Artisanal and Small Scale Gold Mining in Central Kalimantan, Indonesia

**February 2016**

# Abstract

*This report examines the extent and nature of artisanal and small scale gold mining (ASGM) in Central Kalimantan, Indonesia. In the observed areas, landscape change analysis reveals general trends of decreasing dense vegetation/forest, substantial growth of agriculture, and varying degrees of increase for mine affected areas as well as exposed soils. The results of ASGM characterization indicate a variety of techniques employed including dredging, open pit mining, and rock mining. Nevertheless, evidence of active ASGM exploitation is more prevalent in some areas than others. This attests to the dynamic nature of ASGM in the Central Kalimantan region, which may be attributable to the continual discovery of new opportunities for mining, as well as the fact that ASGM is illegal in many of the areas where it occurs.*

# Report Contents

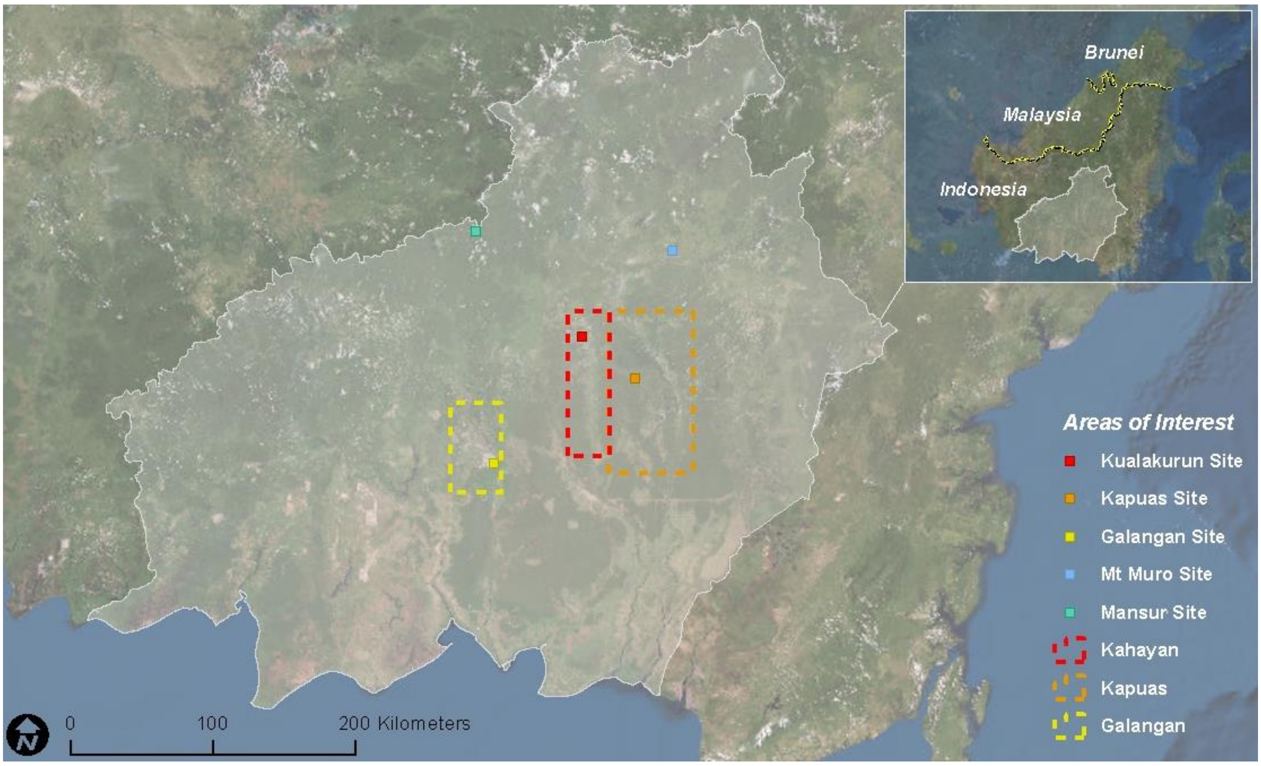
# 1. Introduction

Artisanal and small scale gold mining is a widespread activity that has contributed to deforestation in Indonesia. ASGM in Indonesia consists of techniques such as dredging and open pit mining in which forest and vegetation are cleared. The most significant environmental consequences of ASGM include mercury emissions into the atmosphere and surface waters, as well as deforestation, the loss of organic soil and aquatic habitat, and hydrologic regime changes associated with river siltation and land degradation[1]. This report by the United Nations Institute for Training and Research Operational Satellite Applications Program (UNITAR-UNOSAT) seeks to support to the United Nations Environment Program (UNEP) Chemicals and Waste Branch in assessing the extent and nature of artisanal and small scale gold mining in Central Kalimantan, Indonesia. In addition, the report describes potential methods for longer term monitoring of ASGM activities in Indonesia using satellite imagery.

# 2. Study Area

Central Kalimantan is one of five provinces in Kalimantan, the Indonesian portion of Borneo. Whereas mining had previously been limited to areas along rivers and streams, during the 1990s more widespread ASGM activities emerged in this region. The map below illustrates the location of Central Kalimantan on the island of Borneo, and displays the areas of interest examined in this report. Land cover classification and change analysis were performed for the larger areas, and ASGM equipment as well as techniques were examined for the smaller sites.

*Map 1: Overview Map of Analyzed Areas of Interest in Central Kalimantan, Indonesia*




[1] Telmer K., Stapper D. (2007) Evaluating and Monitoring Small Scale Gold Mining and Mercury Use: Building a Knowledge-base with Satellite Imagery and Field Work. UNIDO Project EG/GLO/01/G34 Final Report.

# 3. Methods

To understand the impacts and nature of ASGM in the study area, UNITAR-UNOSAT conducted satellite imagery analysis to determine the extent of ASGM activities, their contribution to deforestation and evolution over time. Satellite imagery was also used to identify present-day techniques of small scale gold mining in Central Kalimantan. The UNITAR-UNOSAT analysis is comprised of two main products:

- Landscape Change Analysis
- ASGM Characterization

## 3.1 Landscape Change Analysis

Landscape change analysis for two different time periods was conducted for three areas of interest in the Central Kalimantan region. This process first involved the definition of these locations, followed by the selection and acquisition of satellite imagery, processing of the imagery, land cover classification, and finally analysis of changes occurring between the two time periods.

### 3.1.1 Areas of Interest Definition

UNITAR-UNOSAT analyzed satellite imagery collected over the Central Kalimantan region. Three main areas of interest were selected based upon the availability of relatively cloud free satellite imagery, and indications of ASGM activities in the imagery. Preliminary information provided by UNEP on possible locations of interest for the study were also taken into consideration. The following areas of interest, shown in *Map 1*, were chosen given the particular interest in land cover changes associated with mining.

<u>AOI-1: Upper Kahayan Catchment Area</u>

The examined area of the upper Kahayan catchment is located within parts of the Gunung Mas and Kapuas regencies, as well as the Palangka Raya municipality. ASGM activities here consist of alluvial dredging in the riverbank as well as further inland. This area has been heavily deforested as a result of alluvial mining along the catchment.

<u>AOI-2: Kapuas Catchment Area</u>

The analyzed Kapuas catchment area is situated east of the upper Kahayan catchment, primarily within the Kapuas regency as well as parts of the Barito Utara regency and Palangka Raya municipality. ASGM in this region also includes riverbank and catchment area dredging which has resulted in deforestation.

<u>AOI-3: Galangan Site and Katingan Catchment Area</u>

Located to the southwest of the other AOIs, this area is situated in parts of the Katingan and Kotawaringin Timur regencies. It consists of a heavily mined region around the town of Kareng Pangi where large landscape impacts have occurred. ASGM activities have also expanded in the form of alluvial mining along the nearby Katingan watershed.

In order to estimate the recent extent of ASGM activities as well as the evolution, impacts and landscape changes associated with them, satellite imagery from two different time periods was analyzed for each area of interest. Multispectral scenes from the NASA Landsat satellite series were acquired from various dates between 2002 and 2015 (see *Table 1*). These images are freely accessible and provided by the United States Geological Survey (USGS)[2].

*Table 1: NASA Landsat Satellite Imagery Acquired for ASGM Analysis*

| ***Area of Interest*** | ***Sensor*** | ***Date*** | ***Resolution*** |
|---|---|---|---|
| *AOI-1 Kahayan* | Landsat-8 | 3 August 2015 | 30 m |
| | Landsat-5 | 7 August 2005 | 30 m |
| *AOI-2 Kapuas* | Landsat-8 | 3 August 2015 | 30 m |
| | Landsat-5 | 7 August 2005 | 30 m |
| *AOI-3 Galangan and Katingan* | Landsat-8 | 24 September 2014 | 30 m |
| | Landsat-7 | 26 May 2002 | 30 m |

### 3.1.2. Image Processing

**Radiometric Calibration**

Due to the difference of imagery dates, sensors, and acquisition conditions, a radiometric calibration was performed to allow for a consistent comparison of the images. First the original digital values on the images were converted to values of top-of-atmosphere reflectance. The conversion was done using the software ENVI 5.3 based on information about gain, offset, solar irradiance, sun elevation, and acquisition time defined in the metadata of the imagery. Since differing atmospheric conditions existed for each of the images, the effects of atmospheric scattering were removed using the Dark Object Subtraction method as implemented in ENVI 5.3.

**Cloud Cover Extraction**

The Central Kalimantan region experiences high cloud cover throughout the year. Therefore, some portions of the analyzed areas were unfortunately obscured by clouds. Areas in the imagery obstructed by clouds were excluded from the land cover classifications. In order to do an automatic extraction of the cloud obscured areas a threshold based method was used to extract the clouds from the thermal bands and the cloud shadows from the infrared channel.

### 3.1.3. Land Cover Classification

To measure land cover changes, a land cover classification was performed for the different areas of interest using a supervised classification methodology. In the supervised classification method the experience and criteria of the analyst, supported by any available ground information, is used to define the classes by which the land surface is categorized. In order to define different classes the spectral characteristics of land cover present in the imagery were considered, as well as other aspects such as texture, size and position of the different classes.

Once the classes were defined, training fields for each of them were selected in the imagery. These training fields are areas in the imagery chosen for representing characteristics of the different classes well. The training classes are used to assign a land cover class to every pixel in the imagery, according to the algorithm used. For this analysis UNITAR-UNOSAT used the minimum distance classifier method as implemented in ENVI 5.3. *Table 2* provides details of the types of land cover classes used in the analysis.

[2] Sources to obtain Landsat imagery include http://earthexplorer.usgs.gov and http://glovis.usgs.gov

*Table 2: Land Cover Classification Categories for Landsat Satellite Imagery Analysis*

| ***Category*** | ***Land Cover Class*** | ***Description*** |
|---|---|---|
| 1 | *Dense Vegetation/Forest* | Areas dominated by trees/very dense vegetation formation. Includes peatland forests. |
| 2 | *Shrub/Disturbed Forest* | Areas dominated by shrub/non-dense vegetation formation. |
| 3 | *Agricultural Areas* | Includes large scale palm oil plantations and cultivated areas. |
| 4 | *Water* | Areas of open water. |
| 5 | *Exposed Sands/Mining* | Exposed and highly reflective sands/mining tailings. |
| 6 | *Affected Waters/Mining Pits* | Ponds and filled pits within mining areas and waters with high turbidity. |
| 7 | *Exposed Soils* | Bare soil resulting both from vegetation clearing and burning. |

The fifth class – Exposed Sands/Mining – refers to highly reflective deposits that are formed as a result of ASGM tailings. Often located within these areas of exposed sands is an accumulation of affected waters which form ponds or pits, identified within the sixth class – Affected Waters/Mining Pits. The fifth and sixth land cover classes thus represent a direct consequence of ASGM and can be considered as mine affected landscape. The seventh class – Exposed Soils – indicates a precursor for both mining and agricultural activities and is therefore identified separately from the fifth class.

## 3.2 ASGM Characterization

ASGM characterization was performed using high-resolution satellite imagery with a pixel size of 50 centimeters. Imagery was reviewed to directly identify visible ASGM activities by determining common equipment and landscape changes associated with ASGM. Techniques employed for ASGM activities in the Central Kalimantan region of Indonesia vary. According to a 2007 United Nations Industrial Development Organization (UNIDO) project report[3], the following methods have been observed in the country.

*Dredge:* Commonly used on rivers, dredges are powerful machines that excavate earthen materials underwater with a scoop, suction pipe, bucket, or other tool. Sluice boxes may be used in conjunction with dredges to separate gold from gravel or sand. Dredging can result in elevated water sediment loads and subsequently an increased dispersal and transport of naturally occurring mercury.

*Open Pit:* In the open pit method forest is first clear-cut and burned, followed by the use of pumps and hoses to transform sediment into a slurry which is then pumped over carpet covered sluices. Tailings may then form sizeable sand domes and water accumulates in ponds or moves into rivers.

*Ball Mill:* The ball mill method consists of digging tunnels or shafts along veins that contain gold. Ore of a relatively high grade is dug by hand, collected for transport to hammer and ball mills, and subsequently crushed so that gold can then be extracted using an amalgamation of mercury and cyanide.

[3] Telmer K., Stapper D. (2007) Evaluating and Monitoring Small Scale Gold Mining and Mercury Use: Building a Knowledge-base with Satellite Imagery and Field Work. UNIDO Project EG/GLO/01/G34 Final Report.

### 3.2.1 Sub-Areas of Interest Definition

As indicated in *Map 1*, five principal sub-areas of interest in the Central Kalimantan region were selected for ASGM characterization based on availability of imagery with regards to cloud cover, the presence of ASGM signs, and information provided by UNEP. For each location below, an area of roughly 26 square kilometers was examined for evidence of ASGM activity visible in high-resolution satellite imagery.

AOI-1: Kualakurun

Kualakurun is located in the upper Kahayan catchment area, specifically in the southeastern part of the Gunung Mas regency.

AOI-2: Kapuas

Located in the central northern part of the Kapuas regency, this area is part of the larger Kapuas catchment.

AOI-3: Galangan

This is a portion of the Galangan catchment area situated in the central part of the Katingan regency, roughly seven kilometers west of Kasoengan.

AOI-4: Mt Muro

Mt Muro is situated in the southern portion of the Murung Raya regency.

AOI-5: Mansur

Mansur is located in the northeastern corner of the Katingan regency.

For these areas, UNITAR-UNOSAT analyzed high-resolution satellite imagery collected by the GeoEye-1 and WorldView-2 satellites between 2013 and 2015. Details of the imagery selected for each of these areas of interest are specified in the table below. Images were collected by DigitalGlobe, Inc. and purchased through Kongsberg Satellite Services (KSAT).

*Table 3: High Resolution Satellite Imagery for ASGM Characterization Analysis*

| ***Area of Interest*** | ***Sensor*** | ***Date*** | ***Resolution*** |
|---|---|---|---|
| *AOI-1 Kualakurun* | WorldView-2 | 23 June 2014 | 50 cm |
| *AOI-2 Kapuas* | GeoEye-1 | 7 June 2015 | 50 cm |
| *AOI-3 Galangan* | WorldView-2 | 22 September 2013 | 50 cm |
| *AOI-4 Mt Muro* | GeoEye-1 | 9 August 2015 | 50 cm |
| *AOI-5 Mansur* | GeoEye-1 | 2 June 2013 | 50 cm |

# 4. Results

## 4.1. Landscape Change Analysis

Results of the landscape change analysis reveal general trends of declining dense vegetation/forest areas, substantial growth of agricultural areas, and varying degrees of increase for mine affected areas as well as exposed soils in all three AOIs. It is important to note that the total area analyzed for each land cover classification differed. The largest area examined was AOI-2 Kapuas (637,244 ha), followed by AOI-1 Kahayan (278,560 ha), and finally AOI-3 Galangan and Katingan (207,950 ha). Additionally, the difference of dates and time intervals used for the land cover classifications should be taken into account. While satellite imagery from 2005 and 2015 was analyzed for AOI-1 and AOI-2, imagery from 2002 and 2014 was used for AOI-3 as cloud cover was much more problematic in that area. Land cover classification results for each area of interest follow, along with accompanying tables and maps.

Inherent limitations of land cover classification using satellite imagery should also be noted. As this is a relatively rapid land cover classification for a large area, using imagery with 30 meter resolution, and with little access to on-the-ground information for validation, certain errors are unavoidable. For example, in such analyses there will always be misclassified pixels among all land cover types, especially as they transition from one type to another. The separability between classes is not perfect and the simplification of a diverse landscape into a few classes will lead to some small margins of error. While such characteristics and limitations need to be taken into account when examining and making conclusions about the data, UNITAR-UNOSAT feels the analysis results are certainly reliable enough for the purposes intended by UNEP.

AOI-1: Upper Kahayan Catchment Area

In the analyzed portion of the upper Kahayan catchment area (278,560 ha), 16.2% of the dense vegetation/forest area from 7 August 2005 was lost by 3 August 2015. It appears that most of this land (approximately 21,093 ha) was converted for agricultural purposes over the given time period. In addition to the growth of agriculture, the area of exposed sands/mining and affected waters more than tripled between 2005 and 2015, though still remained a very small portion of the overall landscape. Exposed soils also experienced an increase with time. Shrub/disturbed forest land cover decreased by 9.2% compared with its previous area, and water areas rose by 6.6%. *Table 4* contains information specific to each land class in 2005 and 2015, as well as details of the various changes that occurred during this time period.

*Table 4: Land Cover Classification Results for AOI-1*

| ***AOI-1 Kahayan*** | ***7 August 2005*** | | ***3 August 2015*** | | ***Change*** | |
|---|---|---|---|---|---|---|
| *Class* | *Area (Ha)* | *%* | *Area (Ha)* | *%* | *Area (Ha)* | *%* |
| Dense Vegetation/Forest | 172,419 | 61.9 | 144,407 | 51.8 | -28,013 | -16.2 |
| Shrub/Disturbed Forest | 85,331 | 30.6 | 77,462 | 27.8 | -7,868 | -9.2 |
| Agricultural Areas | 10,399 | 3.7 | 31,493 | 11.3 | 21,093 | 202.8 |
| Water | 2,908 | 1.0 | 3,099 | 1.1 | 191 | 6.6 |
| Exposed Sands/Mining | 2,426 | 0.9 | 8,820 | 3.2 | 6,394 | 263.6 |
| Affected Waters | 568 | 0.2 | 1,978 | 0.7 | 1,410 | 248.4 |
| Exposed Soils | 4,510 | 1.6 | 11,302 | 4.1 | 6,792 | 150.6 |

AOI-2: Kapuas Catchment Area

Land cover classifications of the Kapuas catchment (637,244 ha) revealed a 13.6% decrease in dense vegetation/forest area between 7 August 2005 and 3 August 2015. As with AOI-1, a significant portion of this loss was reflected as a gain for agricultural areas which increased by roughly 28,823 hectares. Exposed sands/mining areas also grew considerably from 2005 to 2015 as their size nearly quintupled. Affected waters and exposed soils expanded significantly by 2015 as well. Unlike AOI-1, shrub/disturbed forest experienced a slight increase while areas covered by water were reduced a bit. Specific numbers and percentages as pertains to each land cover class are illustrated in *Table 5*.

Table 5: Land Cover Classification Results for AOI-2

| **AOI-2 Kapuas** | **7 August 2005** | | **3 August 2015** | | **Change** | |
|---|---|---|---|---|---|---|
| *Class* | *Area (Ha)* | *%* | *Area (Ha)* | *%* | *Area (Ha)* | *%* |
| Dense Vegetation/Forest | 481,128 | 75.5 | 415,575 | 65.2 | -65,554 | -13.6 |
| Shrub/Disturbed Forest | 122,181 | 19.2 | 126,301 | 19.8 | 4,120 | 3.4 |
| Agricultural Areas | 11,909 | 1.9 | 40,733 | 6.4 | 28,823 | 242.0 |
| Water | 4,348 | 0.7 | 4,293 | 0.7 | -55 | -1.3 |
| Exposed Sands/Mining | 3,173 | 0.5 | 15,617 | 2.5 | 12,445 | 392.2 |
| Affected Waters | 526 | 0.1 | 1,467 | 0.2 | 941 | 178.9 |
| Exposed Soils | 13,978 | 2.2 | 33,258 | 5.2 | 19,279 | 137.9 |

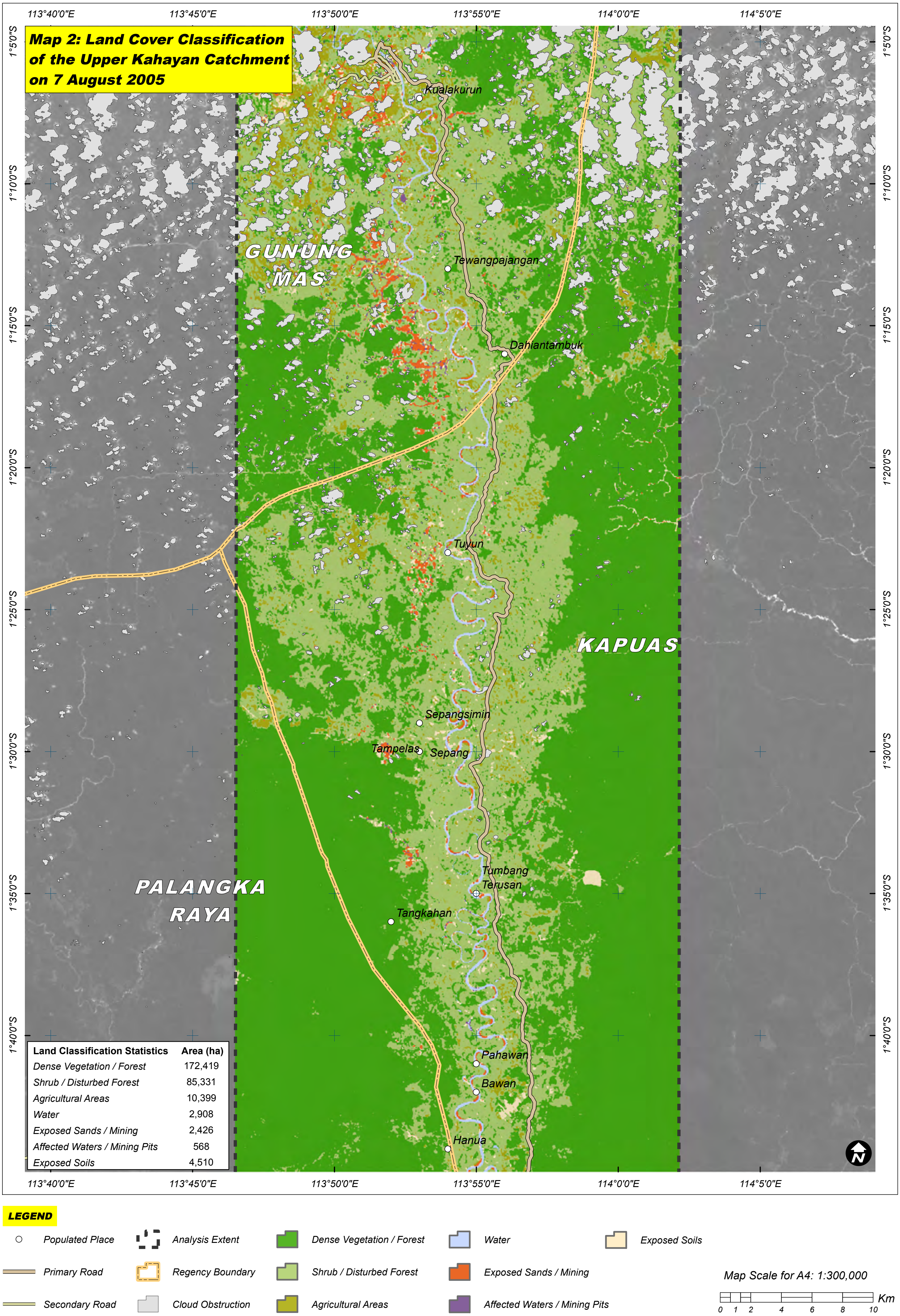
AOI-3: Galangan Site and Katingan Catchment Area

The analyzed area of the Galangan site and Katingan catchment (207,950 ha) experienced the highest relative loss in dense vegetation/forest with the disappearance of 31.5% between 26 May 2002 and 24 September 2014. Shrub/disturbed forest actually declined even more by 47.7%, and open waters decreased by 31.9% over this time period. Agriculture accounted for the large majority of this shift with approximately 43,257 ha of land transformed for cultivation from 2002 to 2014. The expansion of exposed sands/mining and exposed soils also contributed to the overall growth, as well as affected waters though to a much lesser extent. Vegetation recolonized some mining areas in Galangan between 2002 and 2014, however this did not deter the spread of mining activities which persisted in other areas such as along the main river. Detailed information for each land cover class is provided in *Table 6*.

Table 6: Land Cover Classification Results for AOI-3

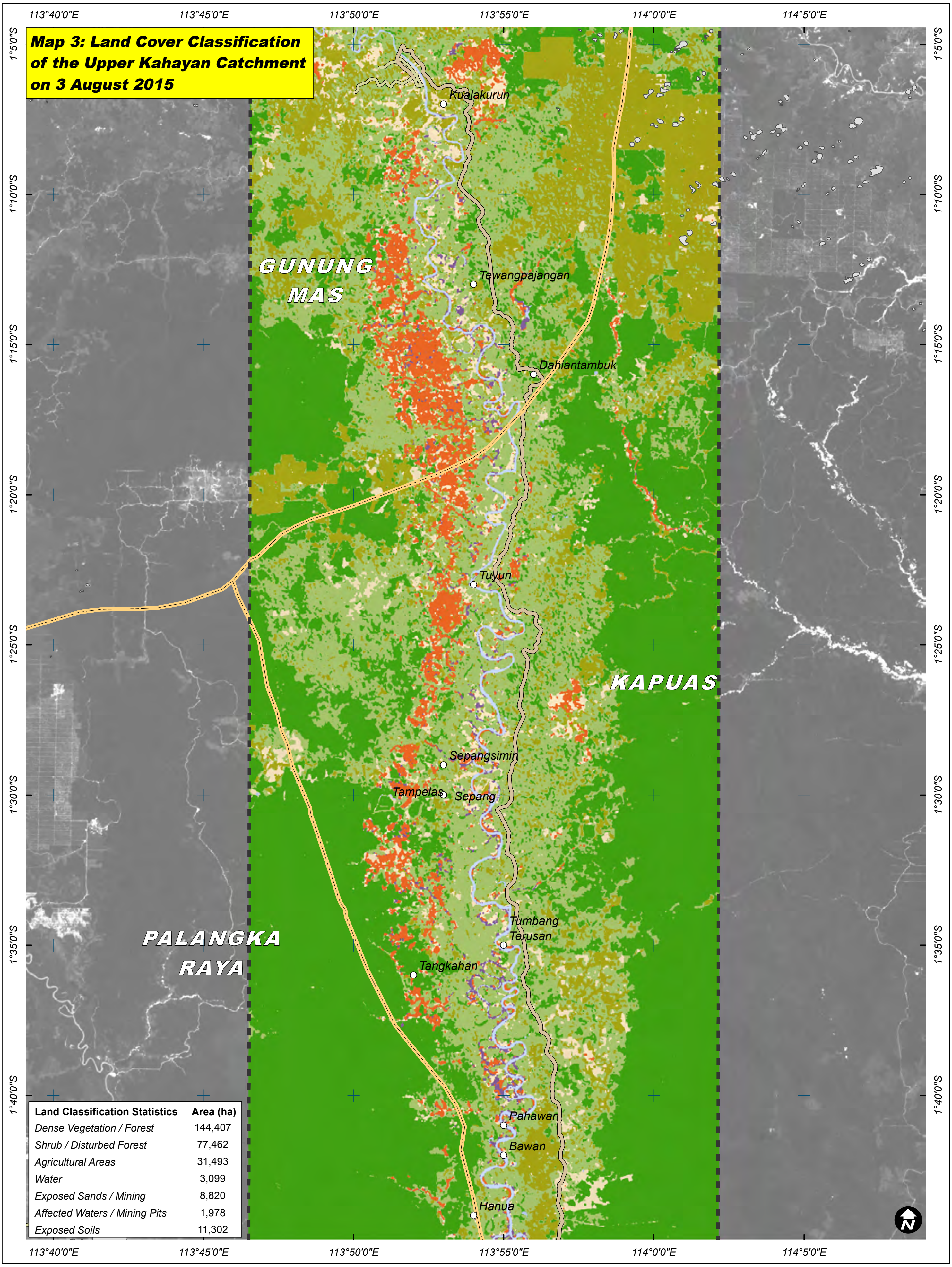
| **AOI-3 Galangan & Katingan** | **26 May 2002** | | **24 September 2014** | | **Change** | |
|---|---|---|---|---|---|---|
| *Class* | *Area (Ha)* | *%* | *Area (Ha)* | *%* | *Area (Ha)* | *%* |
| Dense Vegetation/Forest | 95,976 | 46.2 | 65,703 | 31.6 | -30,274 | -31.5 |
| Shrub/Disturbed Forest | 65,156 | 31.3 | 34,053 | 16.4 | -31,103 | -47.7 |
| Agricultural Areas | 7,477 | 3.6 | 50,734 | 24.4 | 43,257 | 578.6 |
| Water | 2,175 | 1.0 | 1,480 | 0.7 | -695 | -31.9 |
| Exposed Sands/Mining | 9,712 | 4.7 | 15,794 | 7.6 | 6,082 | 62.6 |
| Affected Waters | 608 | 0.3 | 640 | 0.3 | 32 | 5.2 |
| Exposed Soils | 26,847 | 12.9 | 39,546 | 19.0 | 12,700 | 47.3 |

The following pages include land cover classification maps that illustrate landscape changes for all the areas of interest. Three maps are provided for each area, two of which display the land cover associated with the separate aforementioned dates. The third map for each site consists of a comparison of mine affected areas on both analyzed dates. Mine affected areas represent a combination of the exposed sands/mining and affected waters/mining pits land cover classes.




| Land Classification Statistics | Area (ha) |
|---|---|
| Dense Vegetation / Forest | 172,419 |
| Shrub / Disturbed Forest | 85,331 |
| Agricultural Areas | 10,399 |
| Water | 2,908 |
| Exposed Sands / Mining | 2,426 |
| Affected Waters / Mining Pits | 568 |
| Exposed Soils | 4,510 |

## Map 3: Land Cover Classification of the Upper Kahayan Catchment on 3 August 2015



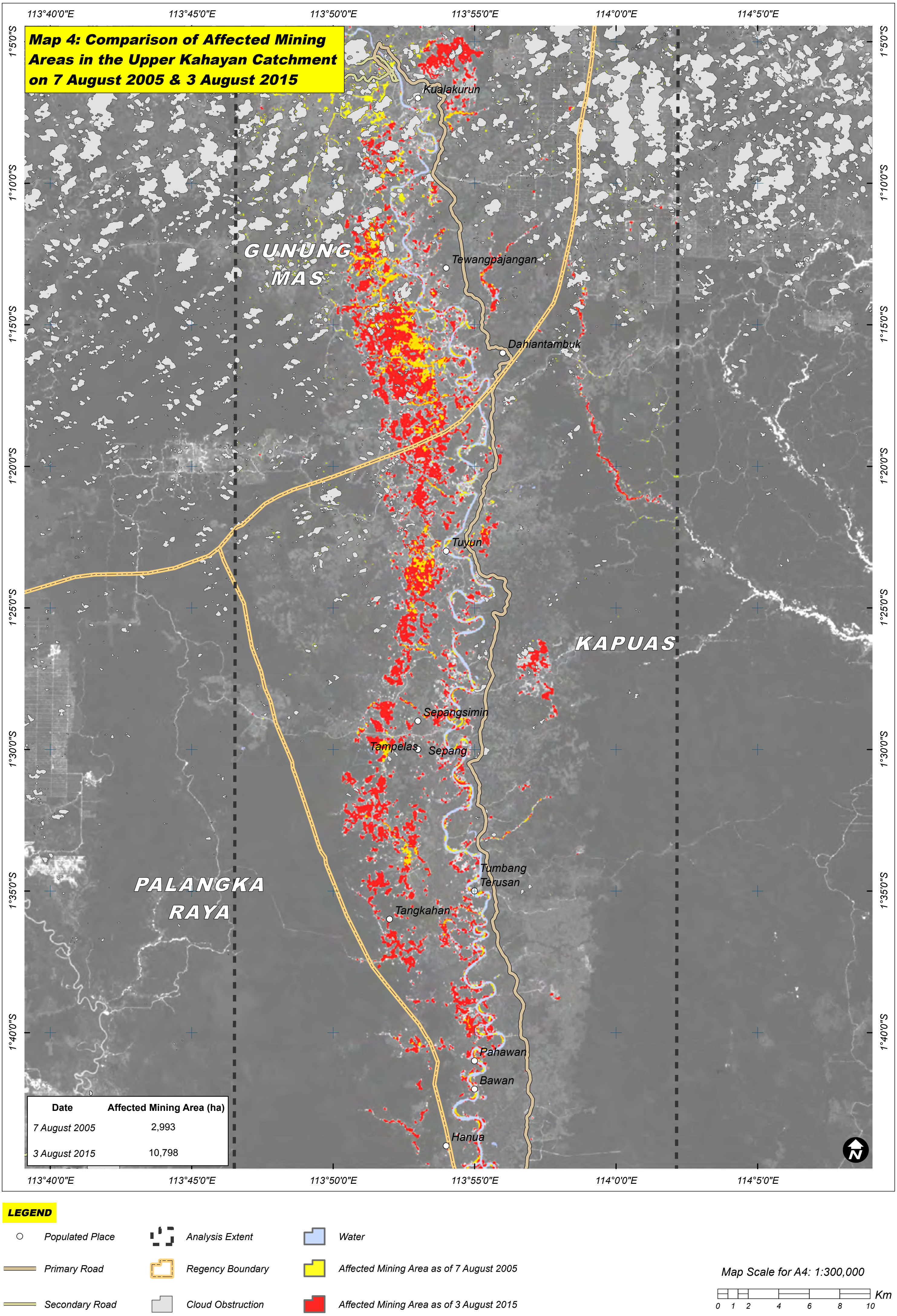

| Land Classification Statistics | Area (ha) |
|---|---|
| Dense Vegetation / Forest | 144,407 |
| Shrub / Disturbed Forest | 77,462 |
| Agricultural Areas | 31,493 |
| Water | 3,099 |
| Exposed Sands / Mining | 8,820 |
| Affected Waters / Mining Pits | 1,978 |
| Exposed Soils | 11,302 |

**LEGEND**

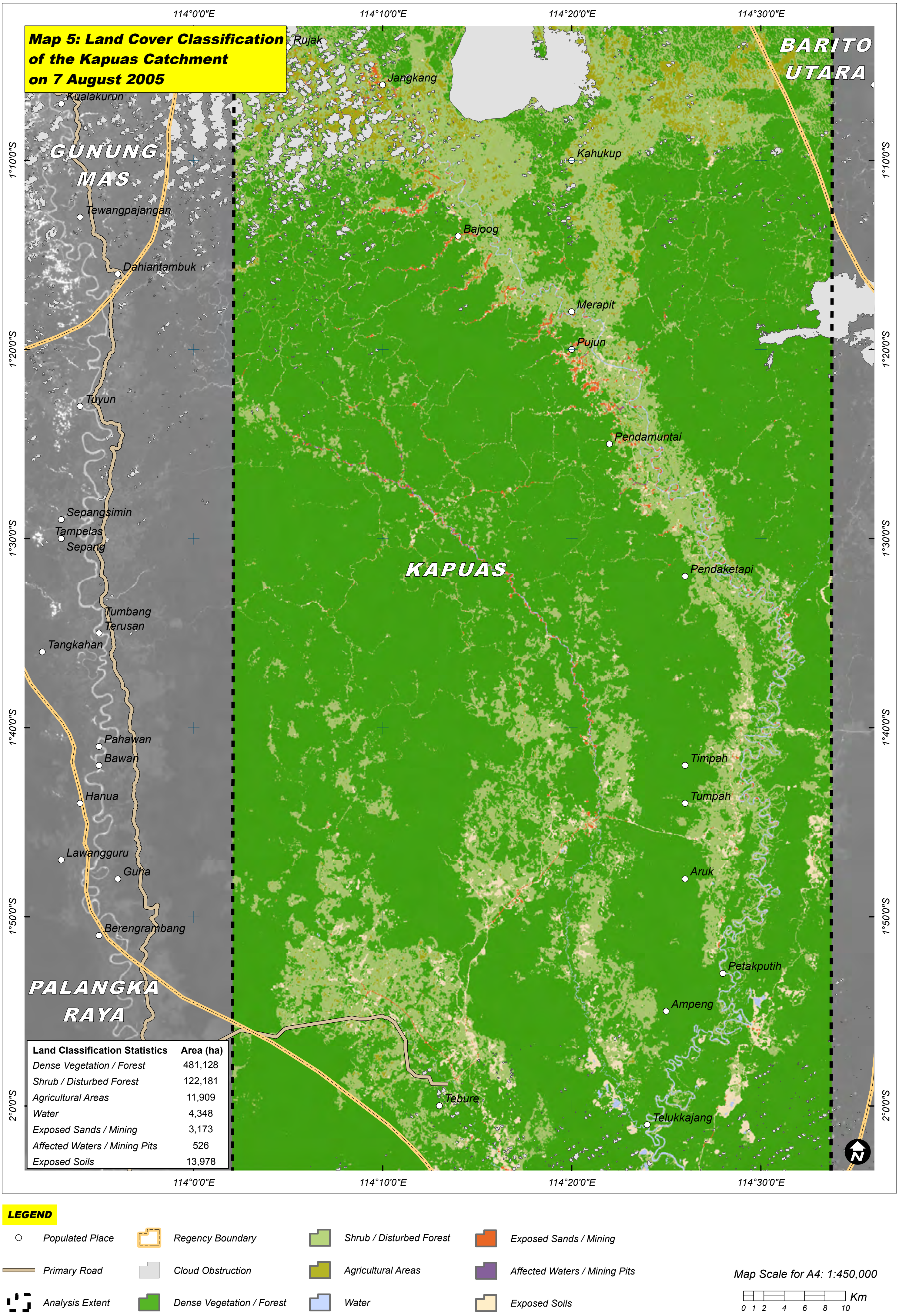
- Populated Place
- Primary Road
- Secondary Road
- Analysis Extent
- Regency Boundary
- Cloud Obstruction
- Dense Vegetation / Forest
- Shrub / Disturbed Forest
- Agricultural Areas
- Water
- Exposed Sands / Mining
- Affected Waters / Mining Pits
- Exposed Soils

Map Scale for A4: 1:300,000

0 1 2 4 6 8 10 Km

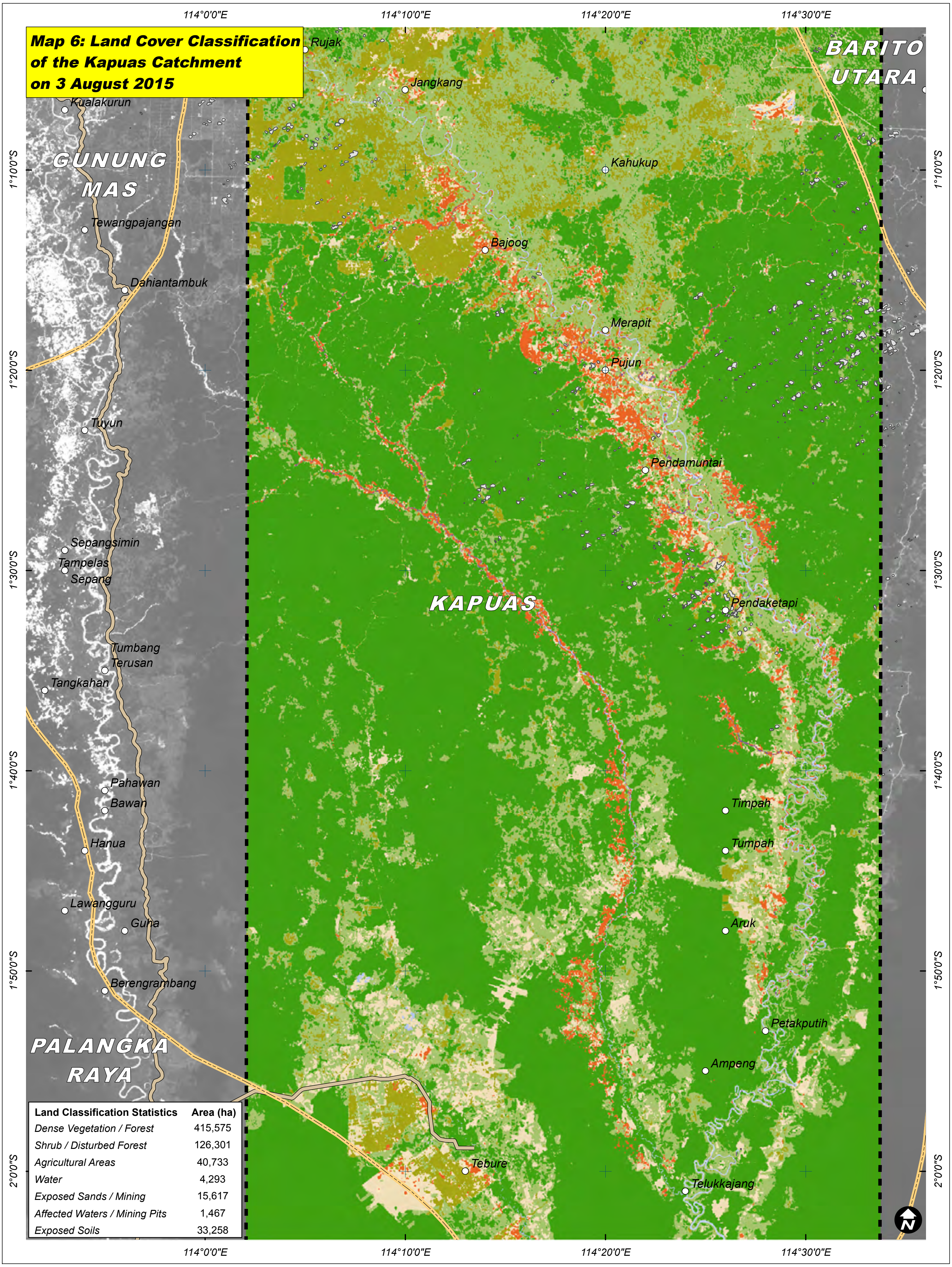



| Date | Affected Mining Area (ha) |
|---|---|
| 7 August 2005 | 2,993 |
| 3 August 2015 | 10,798 |




| Land Classification Statistics | Area (ha) |
|---|---|
| *Dense Vegetation / Forest* | 481,128 |
| *Shrub / Disturbed Forest* | 122,181 |
| *Agricultural Areas* | 11,909 |
| *Water* | 4,348 |
| *Exposed Sands / Mining* | 3,173 |
| *Affected Waters / Mining Pits* | 526 |
| *Exposed Soils* | 13,978 |

**Map 6: Land Cover Classification of the Kapuas Catchment on 3 August 2015**



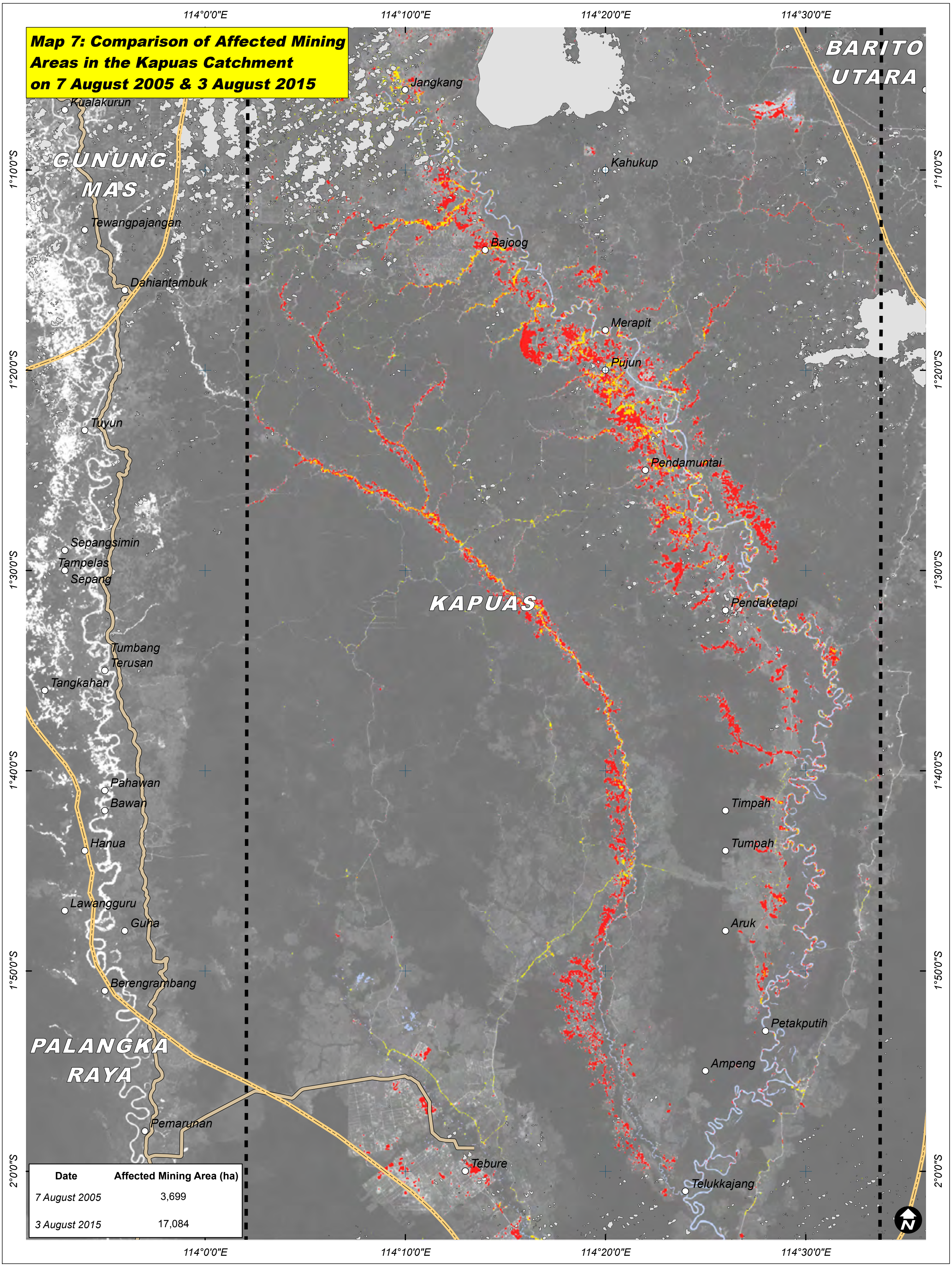

| Land Classification Statistics | Area (ha) |
|---|---|
| *Dense Vegetation / Forest* | 415,575 |
| *Shrub / Disturbed Forest* | 126,301 |
| *Agricultural Areas* | 40,733 |
| *Water* | 4,293 |
| *Exposed Sands / Mining* | 15,617 |
| *Affected Waters / Mining Pits* | 1,467 |
| *Exposed Soils* | 33,258 |

**LEGEND**

*Populated Place*
*Regency Boundary*
*Shrub / Disturbed Forest*
*Exposed Sands / Mining*
*Primary Road*
*Cloud Obstruction*
*Agricultural Areas*
*Affected Waters / Mining Pits*
*Analysis Extent*
*Dense Vegetation / Forest*
*Water*
*Exposed Soils*

*Map Scale for A4: 1:450,000*

Km 0 1 2 4 6 8 10




**Map 7: Comparison of Affected Mining Areas in the Kapuas Catchment on 7 August 2005 & 3 August 2015**

| Date | Affected Mining Area (ha) |
|---|---|
| 7 August 2005 | 3,699 |
| 3 August 2015 | 17,084 |

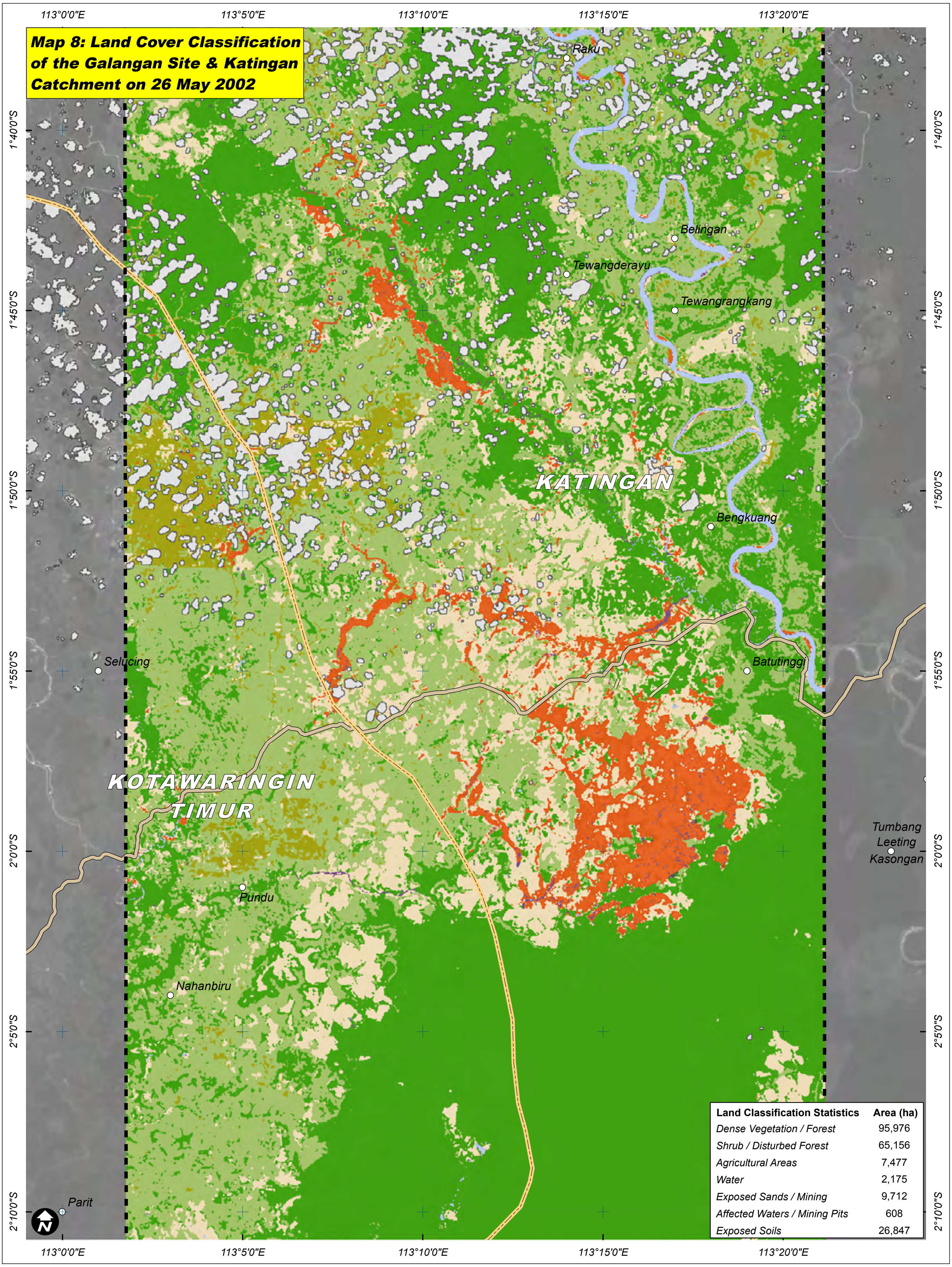
**LEGEND**

- Populated Place
- Primary Road
- Analysis Extent
- Regency Boundary
- Cloud Obstruction
- Water
- Affected Mining Area as of 7 August 2005
- Affected Mining Area as of 3 August 2015

Map Scale for A4: 1:450,000

0 1 2 4 6 8 10 Km

# Map 8: Land Cover Classification of the Galangan Site & Katingan Catchment on 26 May 2002



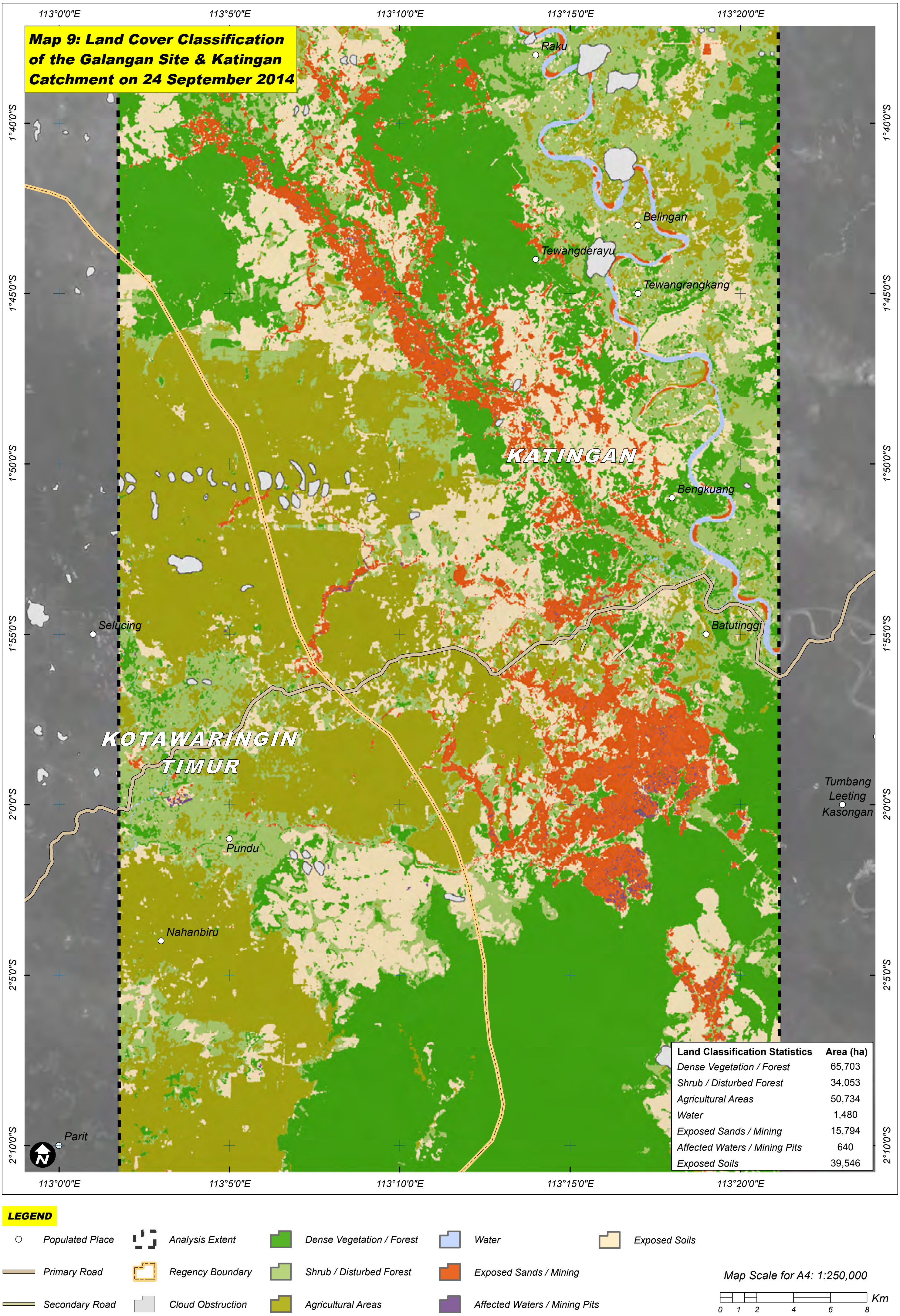

| Land Classification Statistics | Area (ha) |
|---|---|
| Dense Vegetation / Forest | 95,976 |
| Shrub / Disturbed Forest | 65,156 |
| Agricultural Areas | 7,477 |
| Water | 2,175 |
| Exposed Sands / Mining | 9,712 |
| Affected Waters / Mining Pits | 608 |
| Exposed Soils | 26,847 |

**LEGEND**

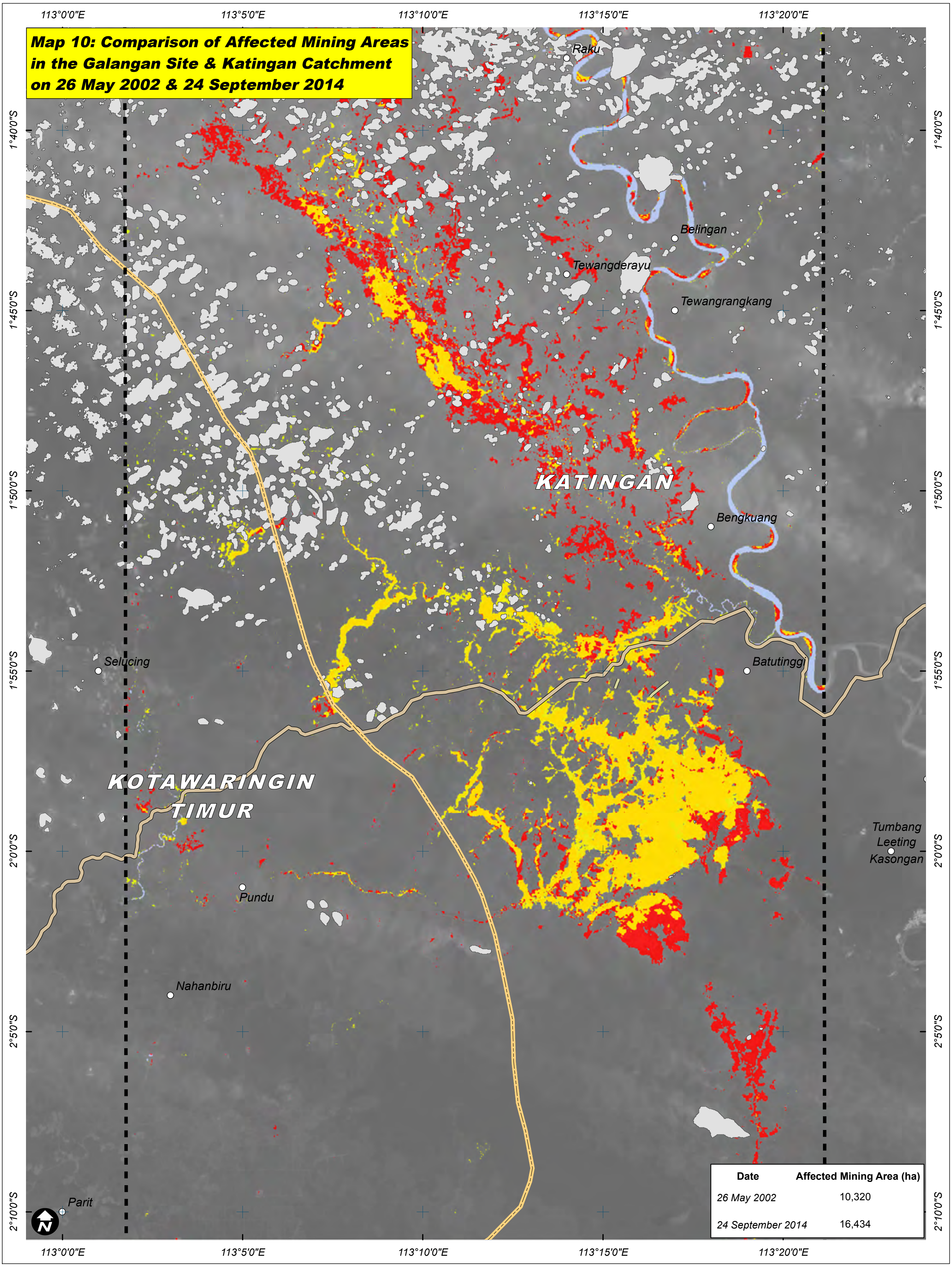
- Populated Place
- Primary Road
- Secondary Road
- Analysis Extent
- Regency Boundary
- Cloud Obstruction
- Dense Vegetation / Forest
- Shrub / Disturbed Forest
- Agricultural Areas
- Water
- Exposed Sands / Mining
- Affected Waters / Mining Pits
- Exposed Soils

Map Scale for A4: 1:250,000

0 1 2 4 6 8 Km




| Land Classification Statistics | Area (ha) |
|---|---|
| Dense Vegetation / Forest | 65,703 |
| Shrub / Disturbed Forest | 34,053 |
| Agricultural Areas | 50,734 |
| Water | 1,480 |
| Exposed Sands / Mining | 15,794 |
| Affected Waters / Mining Pits | 640 |
| Exposed Soils | 39,546 |




**LEGEND**

- Populated Place
- Primary Road
- Secondary Road
- Analysis Extent
- Regency Boundary
- Cloud Obstruction
- Water
- Affected Mining Area as of 26 May 2002
- Affected Mining Area as of 24 September 2014

Map Scale for A4: 1:250,000

0 1 2 4 6 8 Km

## 4.2 ASGM Characterization

Analysis of high resolution satellite imagery acquired in 2013, 2014, and 2015 revealed an assortment of ASGM techniques utilized in the five examined sub-areas of interest. Evidence of dredging, open pit mining, and rock mining were visible. UNITAR-UNOSAT conducted detailed analyses of the Kualakurun, Kapuas, Galangan, Mt Muro, and Mansur sub-areas for signs of ASGM activity. Mining equipment in the form of dredges, dredge-sluice combinations, individual sluices, as well as hoses were identified at different sites. Probable mining camps were observed in all of the locations and more established settlements likely associated with mining activities were also found in some areas. While ASGM appeared to abound in some places, activity was more limited in others either due to a lack of exploited areas or abandoned sites. In some instances, vast expanses of mining pits were observed though relatively little mining equipment was visible. This attests to the dynamic nature of ASGM in the Central Kalimantan region, which may be attributable to the continual discovery of new opportunities for mining as well as the fact that ASGM is illegal in many of the areas where it occurs.

Some limitations of the high resolution imagery analyses should be noted. For instance, in certain configurations dredges resembled mining camp structures and individual sluices were difficult to distinguish from other similarly shaped features such as fallen trees or thin long boats. Due to the dynamic nature of the sites, at times mining equipment likely disassembled for transport was visible and more challenging to categorize with certainty. In short, while active areas of mining were easily identified based on recognizable characteristics of the various infrastructure types, there was some confusion between features like dredges and structures, as well as sluices and other items. Another limitation consisted of cloud obstruction, which was present in each of the high resolution images, and may contribute to an underestimation of ASGM activity. A discussion of the results for each AOI follows, along with accompanying figures and maps.

<u>AOI-1: Kualakurun</u>

UNITAR-UNOSAT analyzed WorldView-2 satellite imagery acquired 23 June 2014 and identified a total of 58 possible sluices, 174 dredges, and 1,056 structures in the Kualakurun sub-area. A vast expanse of mining pits (*Figure 1*) as well as some large patches of deforested areas were visible in the western part of Kualakurun (*Figure 2*). Deforested areas may represent a precursor to future ASGM activity in parts of Kualakurun, particularly since they are located near mining pits. Probable mining camps and equipment (mainly individual sluices) were scattered throughout these pits, though the majority of mining areas appeared to be abandoned. In eastern Kualakurun many dredges in close proximity to the river were observed, as well as several within the river itself. A few established towns were also visible along the river. *Figure 3* shows an example of such activity and part of a settlement located in southeastern Kualakurun. Also visible in the southeastern area of Kualakurun, a tributary flowing into the main river was colored dark brown (*Figure 4*). This is indicative of high dissolved organic carbon content which is a complexing agent of mercury.

*Map 11* illustrates findings from the UNITAR-UNOSAT analysis in a portion of the larger Kualakurun sub-area. It should be noted that within the map the 'dredge' category refers to individual dredges as well as dredge-sluice combinations, and 'sluice' indicates individual sluices. The 'structure' category denotes individual structures that may serve as shelters, gold processing shacks, etc.

AOI-2: Kapuas

GeoEye-1 satellite imagery acquired 7 June 2015 was analyzed by UNITAR-UNOSAT and revealed a total of 39 possible sluices, 206 dredges, and 391 structures in the Kapaus sub-area. ASGM activity in this area mainly consisted of dredging and open pit mining. The majority of active open pit mines were situated along the main river. *Figure 5* displays one such open pit mining area located near a river bank. At such sites it was common to observe dredges composed of a square hut for four or five people attached to a raft with a pumping unit and a long sluice. Several probable mining camps were scattered throughout Kapuas and two larger settlements were also visible alongside the river in the central and southern portions of the AOI. *Figure 6* shows the probable mining settlement in central Kapuas which is situated in close proximity to ASGM activities both upstream and downstream. *Map 12* provides an overview of visible mining equipment and structures in a portion of Kapuas. Open mine pits near the river and some deforested areas in the southern part of the region can also be seen.

AOI-3: Galangan

UNITAR-UNOSAT examined WorldView-2 satellite imagery from 22 September 2013 and identified 15 dredges, 50 possible sluices, and 501 structures in the Galangan sub-area. A general overview revealed a vast array of open mine pits and tailing ponds covering more than half of the Galangan sub-area, and forest occupying the remaining part. *Figure 7* displays part of this patchwork of open mine pits in northern Galangan. A main road traversing the entire sub-area was also visible and as of 22 September 2013 a total of 12 vehicles could be seen travelling on it. Mining camps and small settlements were scattered throughout the affected area, though several were situated along the primary road. *Figure 8* shows an example of such structures located by the road. Relative to the size of the exploited area, ASGM activity appeared to be rather limited. It should be noted, however, that the highly reflective nature of exposed sands in this area caused a significant obstruction of visibility. Nonetheless, as ASGM activities first became widespread in Galangan during the early 1990s, it is possible that many of the mined areas have since been abandoned. *Map 13* provides a visual representation of the ASGM activity observed in a portion of Galangan.

AOI-4: Mt Muro

Analysis of GeoEye-1 imagery acquired 9 August 2015 revealed 6 probable dredges, 5 possible sluices, and 957 structures in the Mt Muro sub-area. This region was visibly dominated by rock mining as opposed to open pit mining or river dredging. A few probable rock mining sites and/or pond tailings were observed in the southern (*Figure 9*), central, and northwestern (*Figure 10*) parts of Mt Muro. Though probable ASGM activity using dredges and sluices was limited in the overall region, most of it was present by open mine pits in the northern part of Mt Muro. Some open mine pits were also visible in southeast Mt Muro, however, there appeared to be little activity. Structures and settlements were scattered throughout the area, with the larger settlements primarily located in the eastern portion of Mt Muro. A sizeable industrial facility was also observed in central Mt Muro. *Map 14* illustrates ASGM related features in central and eastern Mt Muro.

AOI-5: Mansur

Using GeoEye-1 satellite imagery from 2 June 2013 UNITAR-UNOSAT identified 6 probable dredges, 36 possible sluices, and 135 structures in the Mansur sub-area. The majority of the examined region was heavily forested, though a river with numerous open mine pits alongside it and some deforested areas were also visible. Signs of likely ASGM activity were mainly observed near the river, as well as in a few other open locations close to roads or paths. *Figure 11* shows an example of mining pits, possible sluices, and hoses located in a deforested part of northeastern Mansur. *Figure 12* displays a probable mining camp and open mine pits located along the river in central Mansur. *Map 15* provides an overview of ASGM features in part of Mansur.

*Figure 1: Kualakurun (23 June 2014) – Overview of open mine pits in northern and central Kualakurun. A few mining camps are visible, though for its large size there is limited observable mining equipment apart from two dredges and twelve possible sluices.*

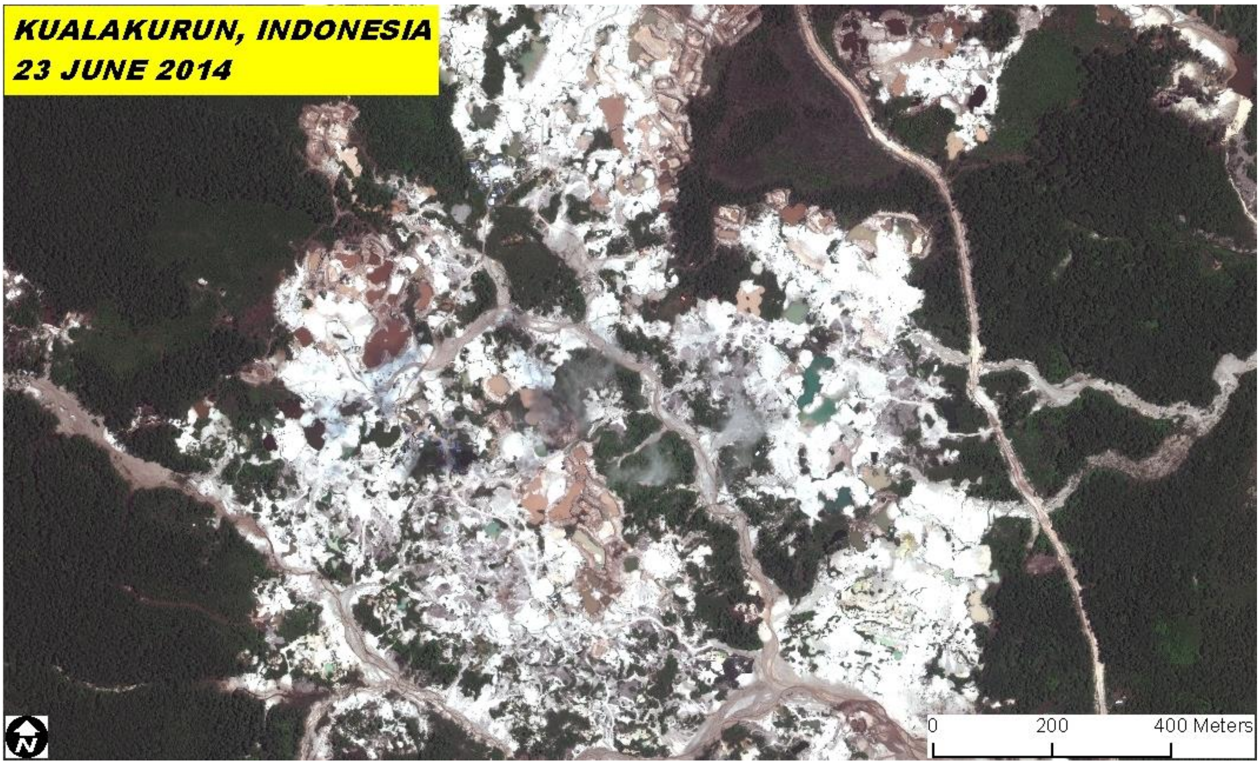
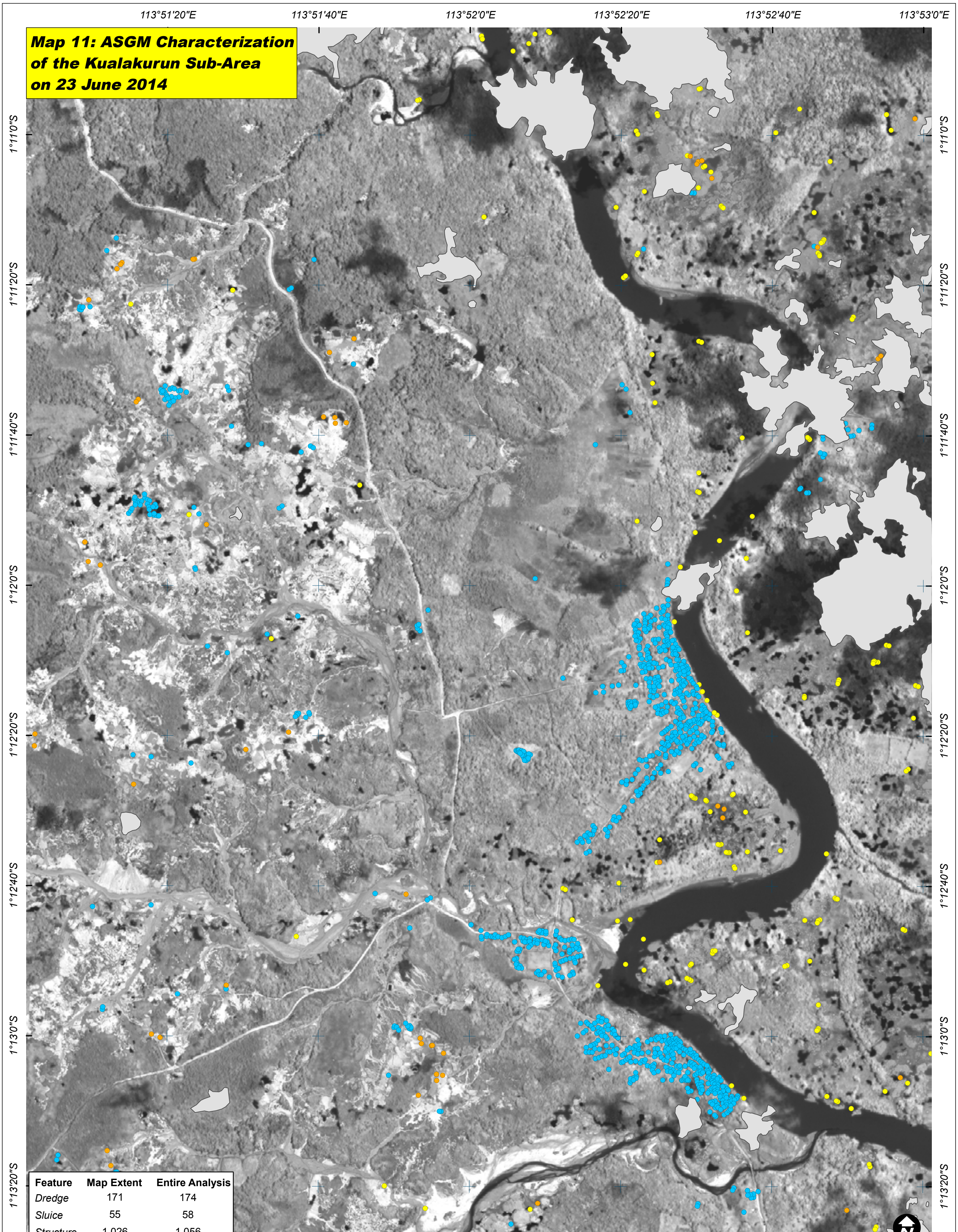



*Figure 2: Kualakurun (23 June 2014) – Deforested areas and nearby mine pits in the northwestern part of Kualakurun. Some structures and possible sluices are also visible. Deforestation may be a precursor to open pit mining.*

*Figure 3: Kualakurun (23 June 2014) – Part of an established mining settlement and nearby mining activity along and within the river in southeastern Kualakurun. A total of 25 dredges and 4 possible sluices are visible in this area.*


*Figure 4: Kualakurun (23 June 2014) - Dark brown water flows from a tributary into the main river in the southeastern portion of Kualakurun. This is a sign of high dissolved carbon content, a complexing agent of mercury.*




| Feature | Map Extent | Entire Analysis |
|---|---|---|
| Dredge | 171 | 174 |
| Sluice | 55 | 58 |
| Structure | 1,026 | 1,056 |

**LEGEND**

- Dredge
- Sluice
- Structure
- Cloud Obstruction

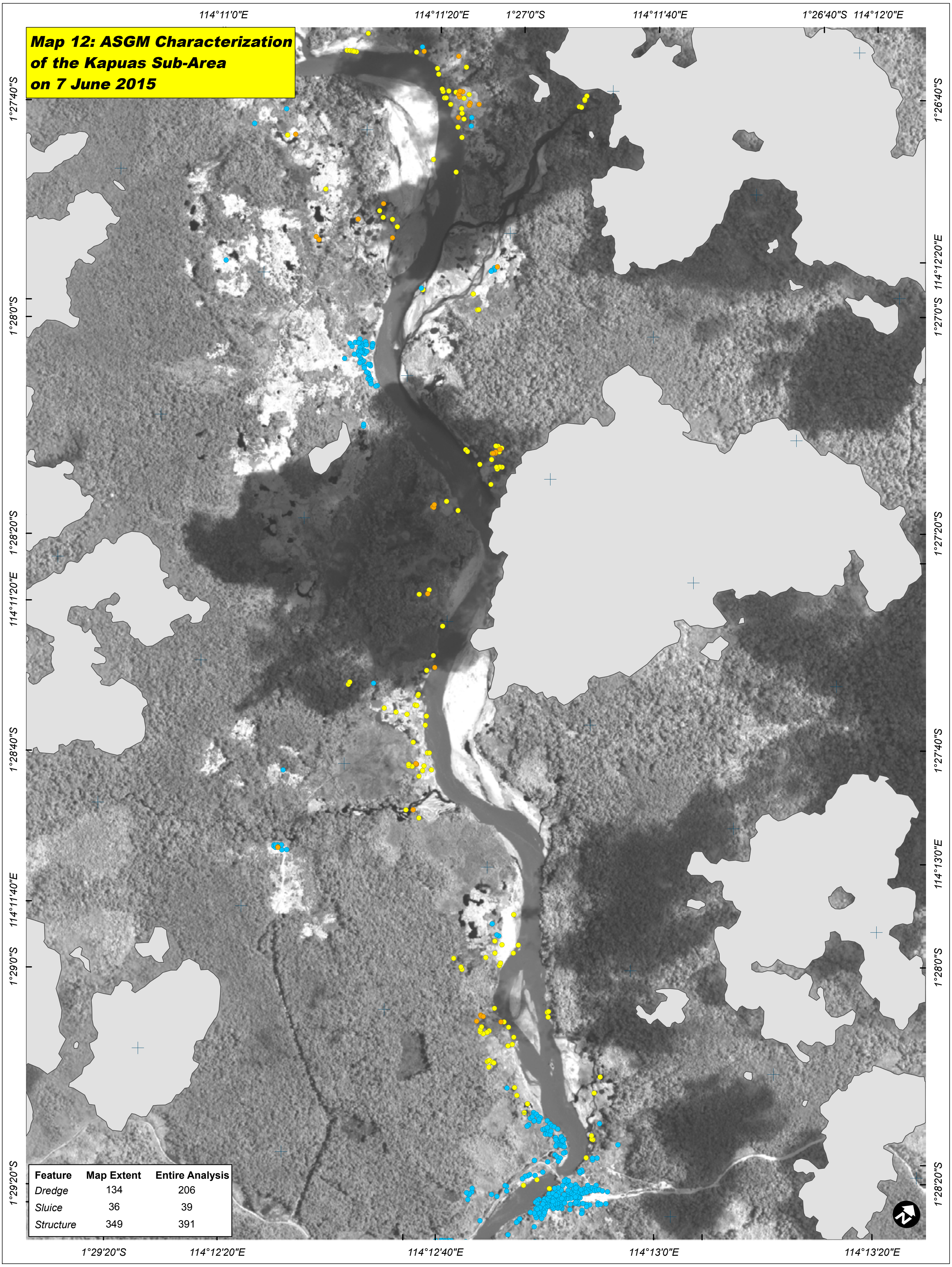
*The depiction and use of boundaries, geographic names and related data shown here are not warranted to be error-free nor do they imply official endorsement or acceptance by the United Nations. UNOSAT is a program of the United Nations Institute for Training and Research (UNITAR), providing satellite imagery and related geographic information, research and analysis to UN humanitarian and development agencies and their implementing partners.*

Map Scale for A4: 1:20,000

0 75 150 300 450 600 Meters

*Figure 5: Kapuas (7 June 2015) – Mining activitiy in the form of dredges along the main river in Kapuas. A total of 13 dredges are visible in this image, many of which are composed of a square hut for four or five people at the end of a raft with a pumping unit and a long sluice.*


*Figure 6: Kapuas (7 June 2015) – A probable mining settlement alongside the main river in the central Kapuas area.*




| Feature | Map Extent | Entire Analysis |
|---|---|---|
| Dredge | 134 | 206 |
| Sluice | 36 | 39 |
| Structure | 349 | 391 |

**LEGEND**

- Dredge
- Sluice
- Structure
- Cloud Obstruction

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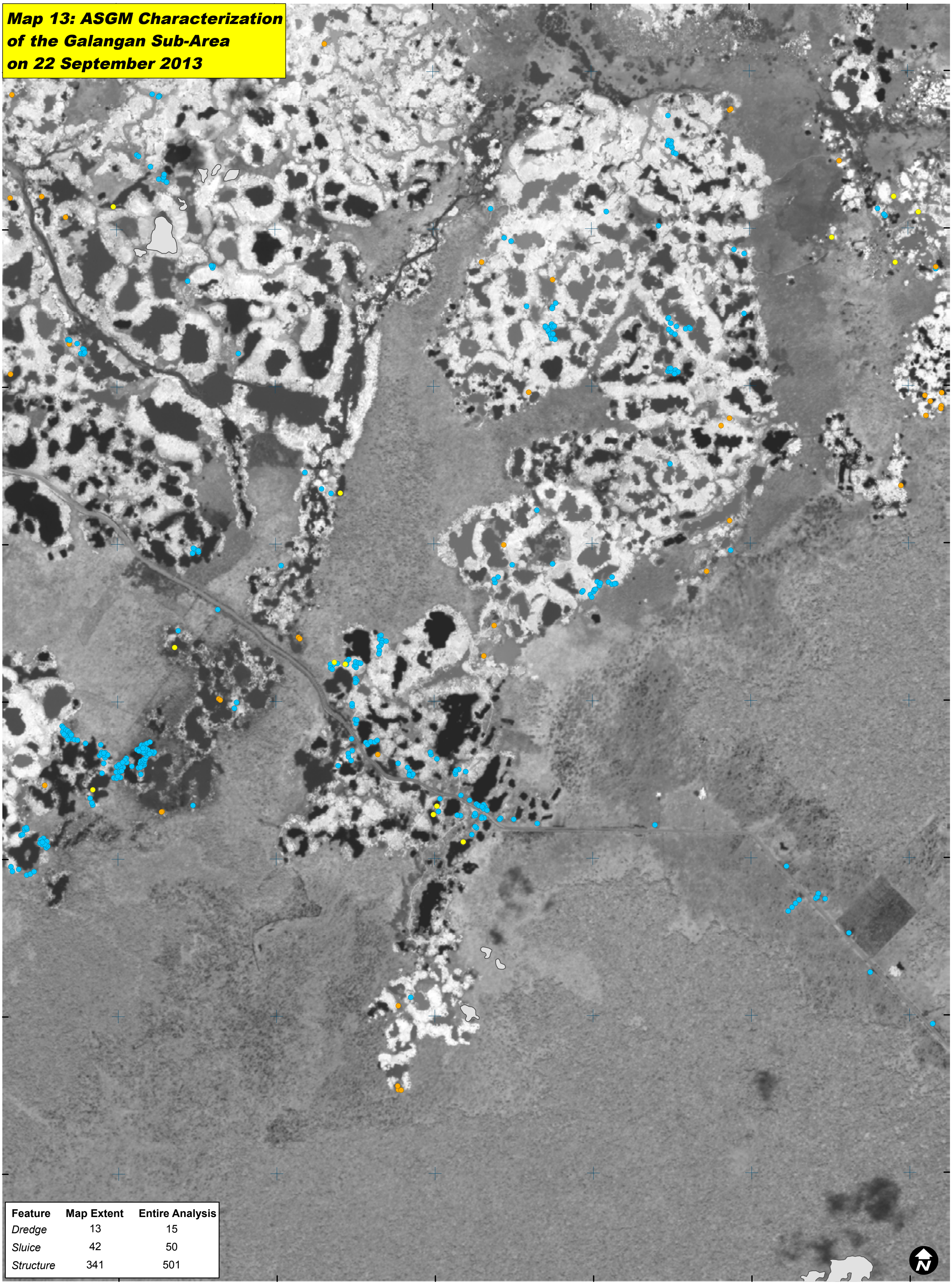
Map Scale for A4: 1:17,000

0 125 250 375 500 Meters

*Figure 7: Galangan (22 September 2013) – Patchwork of open mine pits in northern Galangan. Many of these pits have likely been abandoned as there is little visible trace of ASGM activity in this area.*


*Figure 8: Galangan (22 September 2013) – A small settlement along the main road in northwestern Galangan that is surrounded by open mine pits.*




| Feature | Map Extent | Entire Analysis |
|---|---|---|
| *Dredge* | 13 | 15 |
| *Sluice* | 42 | 50 |
| *Structure* | 341 | 501 |

**LEGEND**

*Dredge*

*Sluice*

*Structure*

*Cloud Obstruction*

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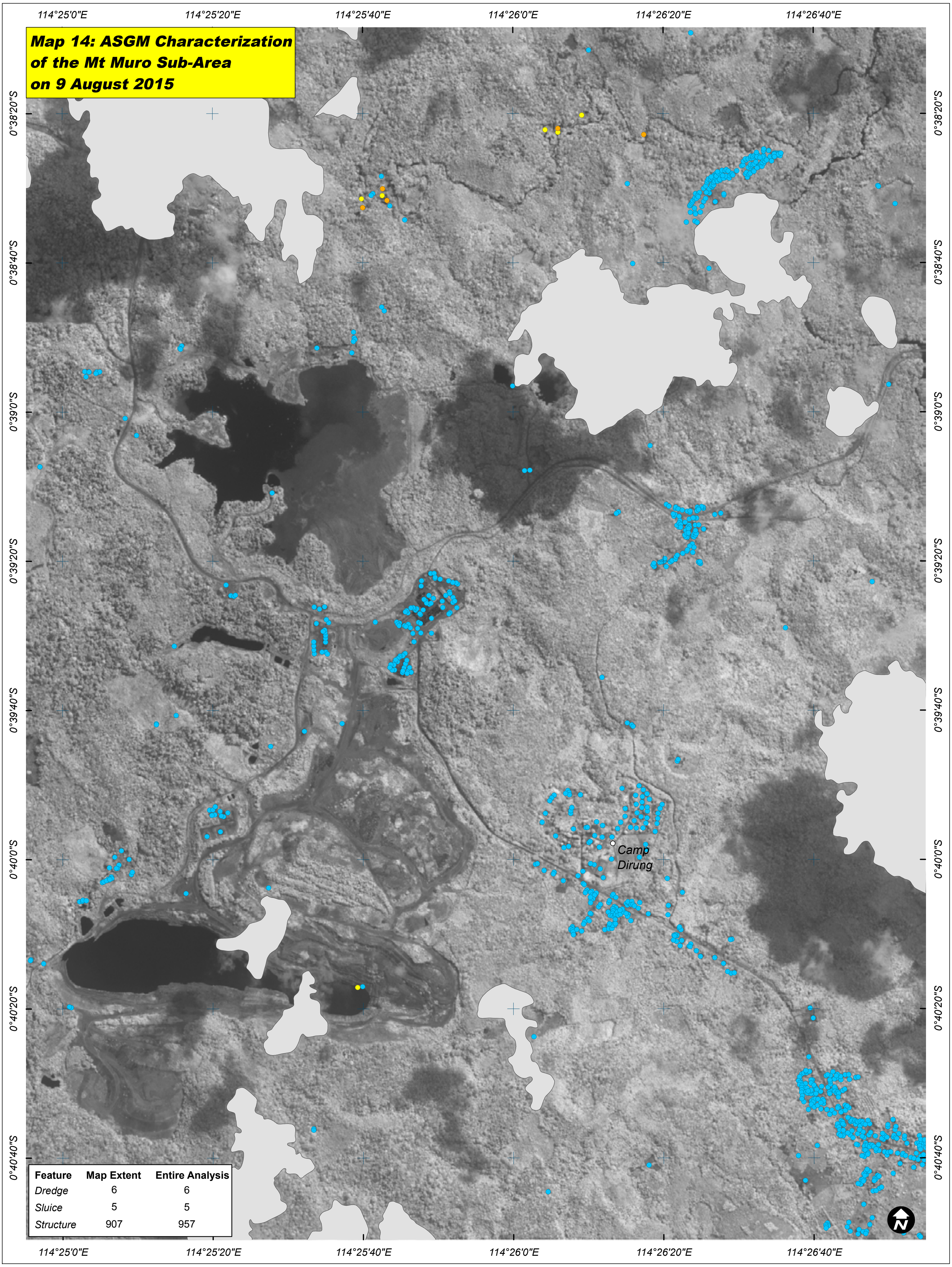
*Map Scale for A4: 1:20,000*

*0 75 150 300 450 600 Meters*

*Figure 9: Mt Muro (9 August 2015) – A probable rock mining site located in southern Mt Muro.*


*Figure 10: Mt Muro (9 August 2015) – Another probable rock mining site and/or tailing pond situated in northwestern Mt Muro.*




**LEGEND**

- Populated Place
- Dredge
- Sluice
- Structure
- Cloud Obstruction

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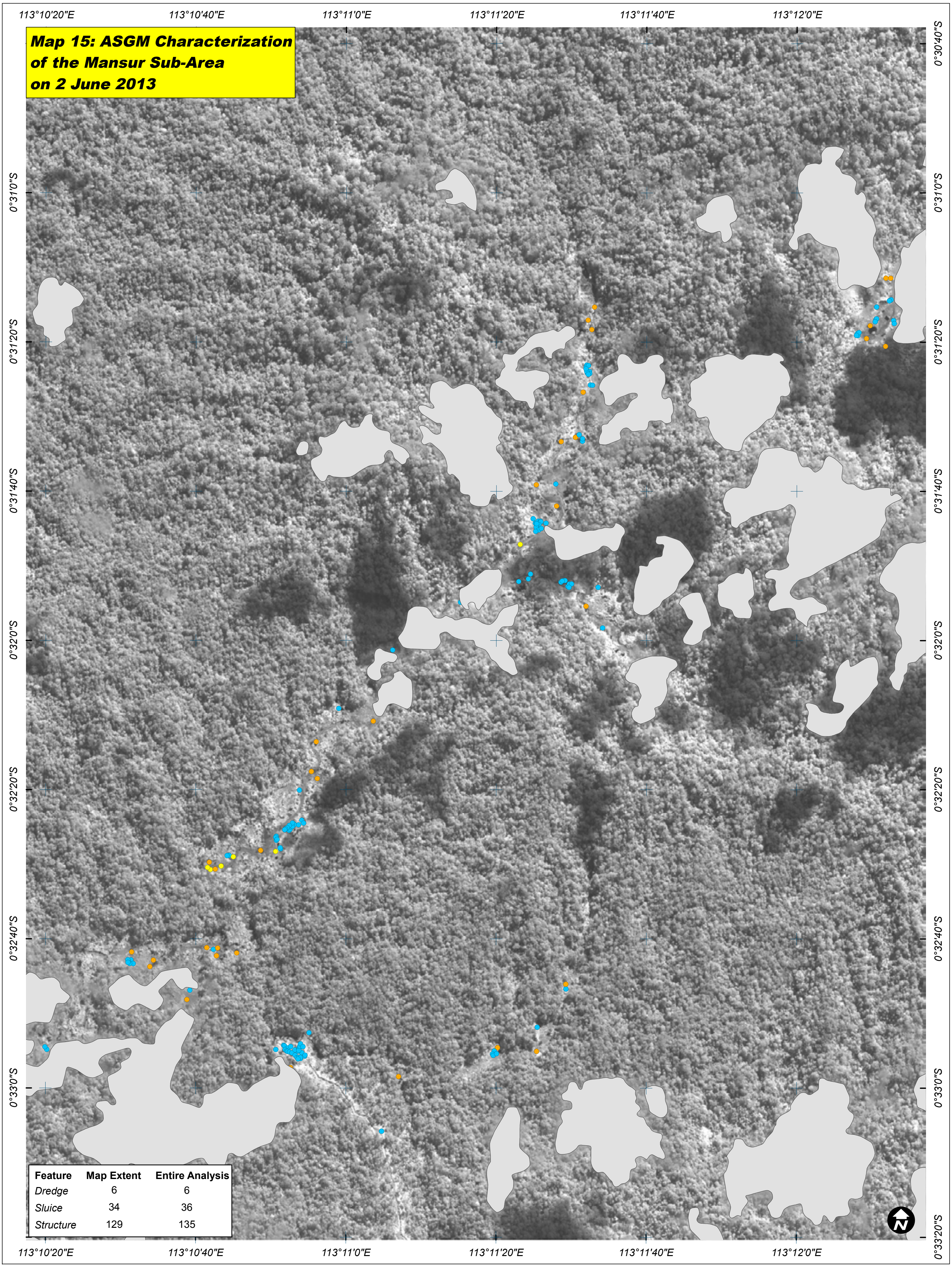
Map Scale for A4: 1:20,000

0 75 150 300 450 600 Meters

*Figure 11: Mansur (2 June 2013) – Mining structures, open pits, possible sluices, and hoses located in a deforested area of northeastern Mansur.*


*Figure 12: Mansur (2 June 2013) – A probable mining camp, open mine pits, and possible sluice located alongside a river in central Mansur.*




| Feature | Map Extent | Entire Analysis |
|---|---|---|
| Dredge | 6 | 6 |
| Sluice | 34 | 36 |
| Structure | 129 | 135 |

**LEGEND**

- Dredge
- Sluice
- Structure
- Cloud Obstruction

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Map Scale for A4: 1:20,000

0 75 150 300 450 600 Meters

# 5. Recommendations for Further Use

Future assessments of ASGM activities in Indonesia with remote sensing has numerous possibilities. As the landscape changes involved in ASGM mining in this area are often dramatic they can be monitored with various kinds of satellite imagery. Use of satellite imagery for such monitoring purposes are well-tested around the world. For example, the Brazilian government maintains the Real Time System for Detection of Deforestation (DETER) to provide weekly updates of areas experiencing new deforestation. DETER is directly used for law enforcement and related purposes. It is based on freely available imagery analyzed by a combination of automated and manual methods. DETER can be considered as a model of national deforestation monitoring using satellite imagery. Monitoring ASGM in Indonesia could incorporate similar methods depending on the desired outcomes. Key questions in the design of a monitoring system include:

1) What is the desired frequency of reporting, i.e. weekly, monthly, or yearly?
2) What is the preferred resolution of reporting, i.e. would only larger landscape changes be of interest or is it necessary to monitor more localized areas in greater detail?
3) What are the resources available?

The primary challenge in using satellite imagery to repeatedly assess areas such as Indonesia will be cloud cover, which is frequent and persistent. For the study presented in this paper, UNITAR-UNOSAT reviewed more than a decade of available Landsat imagery, or more than 260 images for each of the AOIs. Only a few images were found that were not overwhelmingly obscured by clouds and suitable for analysis. Cloud cover will therefore be the primary obstacle for monitoring and will limit the number of optical images which can be utilized for monitoring. While cloud-penetrating radar satellite imagery is also freely available and potentially useful for monitoring, it may not provide the level of detail and confidence found with optical imagery.

An Indonesian monitoring system for ASGM areas could theoretically focus on the two distinct types of land cover change which occur during the mining process. A 'precursor' phase of ASGM mining involves land clearance, often seemingly by fire, which can be monitored using a variety of data and imagery products. The mining phase itself could also be monitored as illustrated in this report. In both cases, the monitoring could be done following a 'nested' model, where low resolution satellite imagery covering the maximum area would be reviewed on regular basis (weekly, monthly, or yearly), and areas of concern then analyzed with higher-resolution imagery as needed. This concept is exemplified in previous pages as UNITAR-UNOSAT first used lower resolution Landsat imagery (30 meter pixel size) to monitor the areas of interest, and then higher resolution commercial satellites with 50 centimeter resolution to focus on the sub-areas of interest.

A monitoring system could make use of the following data sources and images:

- *MODIS optical imagery*: the NASA MODIS sensor is flown on two satellites, provides almost daily imagery for the entire world at 250 meter resolution, and is freely available. Depending on the desired frequency of monitoring, multiple images could be collected and merged to create a cloud free composite for analysis. This may perhaps be done weekly, or more likely monthly. Note, this would only detect more significant deforestation given the 250 meter resolution of the imagery. It is possible that areas of one square kilometer or more would need to be deforested before they could reliably be detected in such imagery. Further testing on this image source would be required to evaluate efficacy.

- *MODIS Thermal Anomaly data*: MODIS imagery is processed by NASA to extract probable thermal anomalies, including fires, at one kilometer resolution. These fire detections are thus intended for larger fires, such as those affecting an area of at least 100 square meters. This data is produced daily and is freely available. It is also affected by cloud cover in that fires will not be detected in areas obscured by clouds. This data could be assessed weekly or monthly to identify trends in burning and attempt to detect the progression of burning across an area, as well as identify new areas of deforestation which may be ASGM related. However, as agriculture and other activities also clear land with fire, some validation of the results would be required to determine the cause of land cover conversion. Additional testing on this data source would be needed to evaluate efficacy.
- *MODIS Burned Area data*: MODIS imagery is also processed by NASA to extract likely burned areas at 500 meter resolution. This data is produced monthly and can be checked to detect expansions of burned areas in proximity to known ASGM sites. Although burned areas may indicate a precursor to ASGM activities, fire is also used to clear land for other activities such as agriculture. Therefore, the results would need to be validated in order to ascertain the origin of the land cover conversion. Notably, clouds may present less of a problem as this product is released monthly, though in an area like Indonesia they will still be a factor in this dataset. Further testing on this data source would also be required to evaluate efficacy.
- *Sentinel-2 optical imagery*: Sentinel-2 optical imagery is freely available from ESA, and is acquired every 5-10 days at 10 meter resolution maximum. Sentinel-2 imagery is similar to the Landsat imagery used in this study and can be analyzed in a similar fashion to monitor and map land cover changes. Clouds will be a limiting factor in use of this imagery.
- *Landsat optical imagery*: The freely available NASA Landsat imagery used in this study can continue to be utilized for further monitoring. Landsat-8, the currently satellite in this series, provides imagery of the same areas every two weeks. Clouds will remain an obstacle to the use of this data.
- *High-resolution commercial optical imagery*: As demonstrated in this report, ASGM activities are directly observable in high-resolution optical imagery. Such imagery is generally purchased and unnecessary for wider area monitoring efforts. Nevertheless, it can provide high levels of detail for smaller areas, as shown in this study.
- *Sentinel-1 radar imagery*: Sentinel-1 radar satellite data is freely available from the European Space Agency (ESA), and is acquired every 10-20 days at roughly 10 meter resolution. Radar satellite data can penetrate through clouds which is a significant benefit in Indonesia. Nonetheless, specific types of land cover change can be difficult to determine from radar imagery analysis. The imagery may, however, be useful to monitor known ASGM areas and some aspects of their change. Importantly, radar imagery can be processed to identify burned areas with greater confidence. Thus the aforementioned burned area analysis can be conducted to identify areas of land cover conversion potentially related to ASGM activities. This data source would need to be tested further in order to evaluate efficacy.

Several of these data sources may be used in conjunction with one another to periodically map ASGM activities in areas of interest. For example, monthly review of NASA burned areas can identify broad patterns of change within AOIs, to be followed by review of Landsat or Sentinel-2 imagery to delineate ASGM activities, and occasional acquisition of high-resolution imagery can then identify specific methods of mining. Some experimentation would be required to design the optimal configuration and use depending on resources available. Specifically, an organization like UNITAR-UNOSAT would need to interact with potential users of this monitoring system in order to learn of their needs and specifications. Further examination of the above sources of satellite imagery and data would be required to test processing and analysis times, the effects of persistent cloud cover, possibilities for radar analysis, etc. The results of this testing phase would then inform the development of a monitoring system comprised of the most appropriate satellite imagery and data sources. These would be analyzed by qualified individuals, and the results delivered at specified time intervals in a format that is most useful to partners.

In addition to the limiting role played by clouds in this area, a key consideration for an ASGM monitoring system will be available funds or human resources. While many of the potential data sources are free their analysis is quite time consuming. However, remote sensing skills are also quite widespread and so it is possible that elements of the Indonesian government or academic institutions can provide necessary labor.

# 6. Conclusion

Based on satellite imagery analysis, this report has provided an assessment of the extent, nature, and evolution of artisanal and small scale gold mining in parts of Central Kalimantan, Indonesia. Landscape change analyses of the Kahayan, Kapuas, and Galangan areas revealed general trends of declining vegetation/forest areas, significant growth of agricultural areas, and varying degrees of increase for mine affected areas as well as exposed soils. A closer examination of the Kualakurun, Kapuas, Galangan, Mt Muro, and Mansur sub-areas confirmed the presence of ASGM activities in the form of dredging, open pit mining, and rock mining. Probable mining camps as well as more established settlements likely associated with mining activities were also observed.

To assess the dynamics and consequences of Indonesia's ASGM activity in the future, monitoring efforts can incorporate remote sensing techniques and a variety of satellite imagery types. Depending on the primary objective and available resources the state of ASGM in different parts of the country could be assessed over time and reveal larger landscape changes and/or more detailed accounts of activities in smaller areas. Through such efforts, the information needed to adequately comprehend and effectively manage ASGM in Indonesia would be available for all relevant actors with a stake in the country's environmental, economic, and social well-being.

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