INUNDATION AND WATER LEVEL DYNAMICS OF THE MAHAKAM CASCADE LAKES FROM SATELLITE RADAR AND ON-GROUND OBSERVATIONS

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ABSTRAK

Danau-danau di Mahakam tengah merupakan bagian dari lahan basah di Kalimantan Timur yang memiliki peran penting secara ekologis. Informasi mengenai dinamika genangan danau diperlukan sebagai data dasar untuk kajian terpadu mengenai banjir, proses ekologis, dan kerentanan sistem untuk perencanaan, disain, pelaksanaan kebijakan pengelolaan lahan dan langkah-langkah mitigasi. Penginderaan jauh dengan radar sangat cocok untuk identifikasi, pemetaan, dan pengukuran di lahan basah tropis karena tidak terganggu oleh tutupan awan dan dapat bekerja baik siang maupun malam. Penelitian ini bertujuan untuk mempelajari dinamika genangan danau-danau kaskade Mahakam (Jempang, Semayang, Melintang) dari serangkaian citra radar dan pengukuran kedalaman danay dan tinggi muka air di lapangan. Serangkaian citra PALSAR (Phased Array L-band Synthetic Aperture Radar) dari tahun 2007—2010 dikoleksi untuk studi ini. Pengukuran tinggi muka air dilakukan dengan menggunakan transduser tekanan selama periode April 2008 sampai Agustus 2009. Selama periode ini, bariasi tinggi muka air danau mencapai 3.5 m. Pengukuran batimetri danau dilakukan dengan menggunakan echo-sounder. Variasi luasan danau diperoleh dari evaluasi nilai backscatter radar terhadap nilai ambang backscatter radar untuk area perairan terbuka. Dari statistik backscatter radar area danau dan sungai yang diketahui memiliki genangan permanen, diperoleh nilai ambang -25.1 to -11.2 dB untuk deteksi genangan pada perairan terbuka. Peta luasan danau yang diperoleh dari serangkaian citra PALSAR menunjukkan variasi area genangan yang cukup tinggi pada danau-danau Mahakam. Tingginya variasi ini berhubungan dengan karakteristik danau-danau tersebut sebagai danau paparan banjir.

***Kata Kunci**: dinamika genangan, danau-danau mahakam, tinggi muka air, batimetri, radar*

ABSTRACT

Lakes in the middle Mahakam area are part of an ecologically important wetland in East Kalimantan. Information on lake inundation dynamics is required as baseline data for integrated assessment of flood dynamics, ecological processes, and vulnerability required in planning, designing, and operating land management policies and mitigation measures. Radar remote sensing is well-suitable for identification, mapping, and measurement of tropical wetlands, for its cloud unimpeded sensing and night and day operation. We aim to gain insight into inundation dynamics of the Mahakam cascade lakes (Jempang, Semayang, Melintang) from a series of radar images and on-ground lake depth and water level measurements. We collected a series of PALSAR (Phased Array L-band Synthetic Aperture Radar) images in the years 2007—2010. Water level measurements were carried out at the lakes using pressure transducer from April 2008 through August 2009. The amplitude of lake water level variation exceeds 3.5 m. Bathymetry measurements were carried out using a single beam echo-sounder. Variation of lake extent was obtained by evaluating radar backscatter values against a threshold for open water area. From statistics of radar backscatter over regions covering the permanently inundated river and lakes, we obtained a threshold value of -25.1 to -11.2 dB for open water flooding detection. The lake extent map *obtained from PALSAR image series showed there is a large variation in inundation area of the Mahakam lakes. Such a large variation is attributed to their nature as floodplain lakes.*

***Keywords**: inundation dynamics, Mahakam lakes, water level, bathymetry, radar*

INTRODUCTION

Lakes in the middle Mahakam area (Fig. 1) have a vital role in discharge regulation for the lower Mahakam region. They have a function as a buffer to store water during the high flow condition and release it during low flow. Three main lakes in the middle Mahakam area known as the Mahakam cascade lakes are Semayang, Melintang, and Jempang lakes. Water level records at locations upstream of the Mahakam lakes area in Melak, in lake Jempang, and downstream of the Mahakam lake area in Muara Kaman indicate that some peaks of water level were shaved by the lake filling and emptying mechanism (Hidayat, 2011). However, due to data unavailability, the lake buffering effect has not been quantified to date. Information on lake inundation dynamics is required as baseline data for integrated assessment of flood dynamics, ecological processes, and vulnerability required in planning, designing, and operating land management policies and mitigation measures. This study aims to gain insights into inundation dynamics of the Mahakam cascade lakes from a series of radar images and on-ground lake depth and water level measurements.

Data scarcity in the spatial and temporal domains is imminent issue in an ungauged basin such as the Mahakam catchment. Remote sensing is considered to be a solution to many problems in hydrology by the current trend of ever increasing data availability.Radar remote sensing has a special role in this issue as it is unconstrained by cloud cover and day and night functioning. Most surface water features are detectable on radar imagery because of the contrast in return between the smooth water surface and the rough land surface (Lewis, 1998).These advantages support the suitability of radar technology for hydrological application in the humid tropics.

Time series of L-band radar data such as the JERS-1 images have been applied to acquire information on the hydrology in peat swamps (Hoekman, 2007). Synthetic aperture radar (SAR) with all weather and day and night capabilities as well as the specular reflection of microwaves from open smooth water bodies resulting in dark tones on the image can be used to evaluate 1D or 2D flood inundation models (Schumann et al., 2008).Combination of Shuttle Radar Topography Mission (SRTM) data, time series of JERS-1 images and field measurement can be applied to study the temporal dynamics of lake water mixture and fluxes between the river and floodplain along the river (Bonnet et al., 2008).

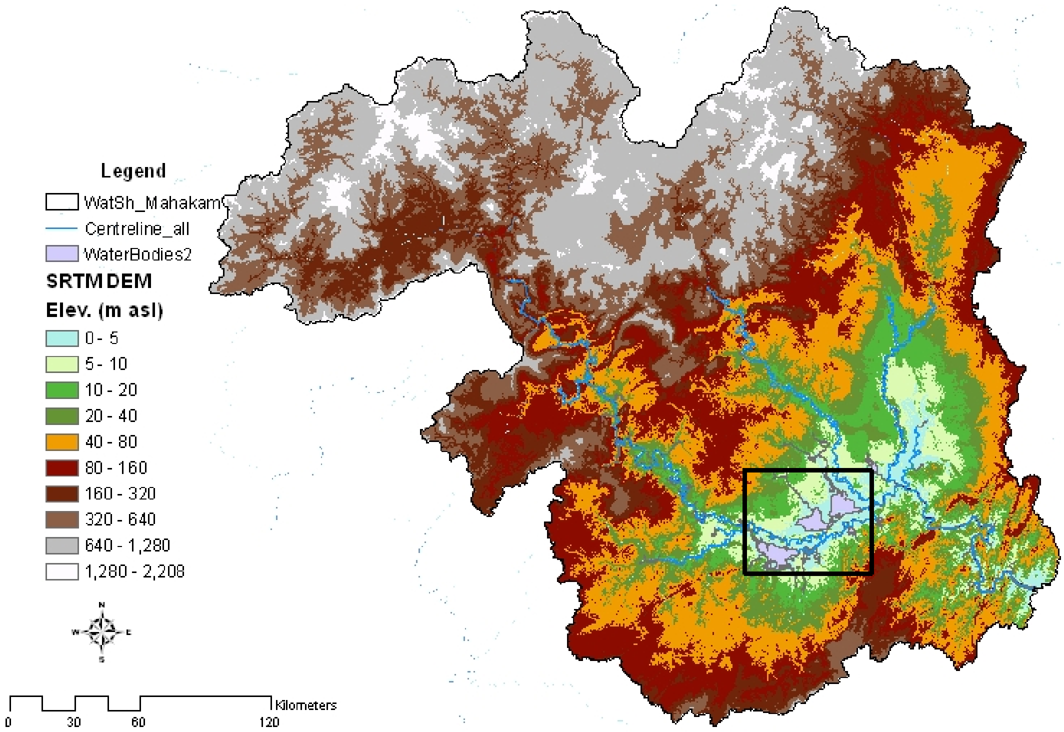

Fig. 1. The Mahakam catchment upstream of the delta apex plotted on a digital elevation model obtained from SRTM data. The rectangle indicates the study area.

METHODS

Water level measurements were carried out at the lakes using pressure transducer from April 2008 through August 2009 at locations described in Table 1. The pressure transdusers were placed in a PVC tube on the level that they are not flooded during high water condition Fig. 2. Bathymetry measurements were carried out by navigating across the lake using a single beam echo-sounder at a relatively coarse resolution of about 500 m (Fig. 3).

Table 1. Water level measurement locations at the Mahakam cascade lakes.

No	Location	Lat (S)	Lon (E)	Descriptions
1.	Pela Semayang	0.239	116.536	WL in the channel (village) near L. Semayang
2.	Lake Melintang	0.293	116.270	WL near Teluk Tuk peat at L. Melintang shore
3.	Lake Jempang	0.496	116.188	WL In village Pulau Lanting at the shore of L. Jempang

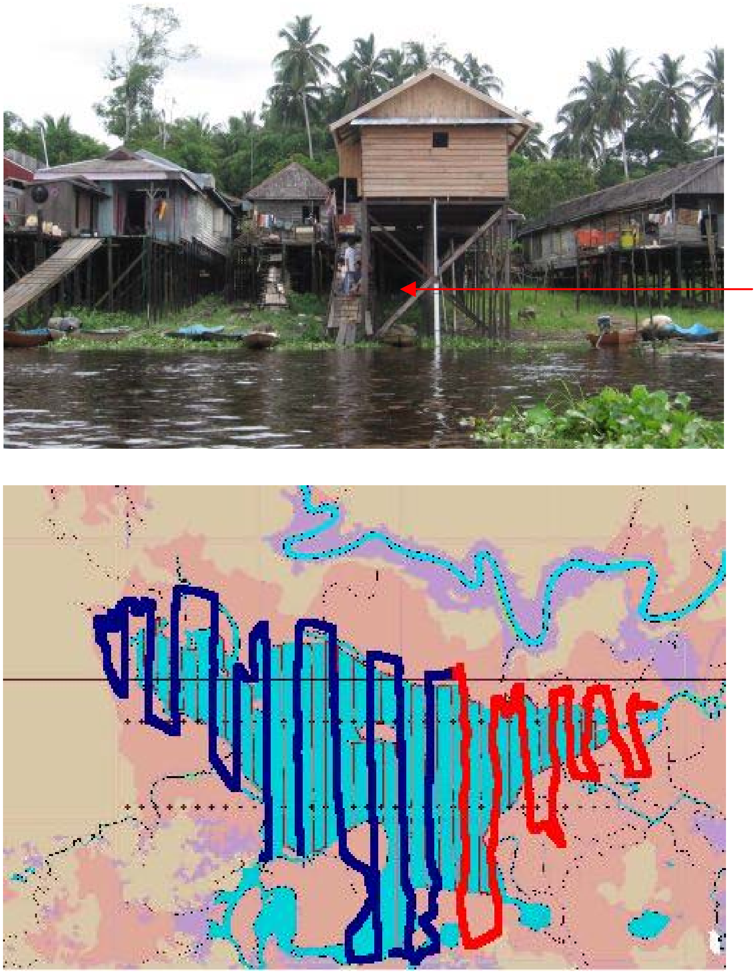

Fig 2. (top) Location of water level measurement at the shore of Lake Jempang. The arrow indicates the PVC tube that holds the pressure sensor. (bottom) Bathymetry tracks at lake Jempang taken during high water period of March 2009.

A series of PALSAR (Phased Array L-band Synthetic Aperture Radar) images in the years 2007—2010 are collected. The PALSAR images covering the Mahakam lakes area with a pixel spacing of 75 m was provided by the Japan Aerospace Exploration Agency (JAXA). The images were radiometrically calibrated, orthorectified using 3" SRTM data and corrected for slope illumination effects. These geocoded data were then chronologically stacked into a layered multi-temporal radar image suitable for time-series analysis. We carried out the Principal Component Analysis (PCA) to reveal the inundarion dynamics of the study area from combination of multi temporal PALSAR images. Variation of lake extent was obtained by evaluating radar backscatter values against a threshold for open water area. From statistics of radar backscatter over regions covering the permanently inundated river and lakes (Hidayat, 2012), a threshold value of -25.1 to -11.2 dB was used for lake inundation detection. The flood frequencywas determined by evaluating pixels in the images used as input against the lower and the upper threshold values. The pixel was flagged as flooded if its backscatter value falls within the range of the lower and upper thresholds. An image with pixel values of counts of the flooded flag was obtained, which was then color mapped. Herein, flood frequency is defined as a sum of flood counts encountered in each image pixel based on the evaluation of PALSAR time series.

RESULTS AND DISCUSSION

On-ground measurements

Figure 3 shows water level at Lake Jempang during the measurement period. Similar water level patterns are obtained for lake Semayang and Melintang. The amplitude of lake water level variation exceeds 3.5 m indicating a huge ammount of water is stored in the Mahakam cascade lakes along with other smaller lakes and their adjacent floodplain areas during high water period. Figure 4 shows bathymetry of Lake Jempang interpolated from lake depth measurements in March 2009. Overall, there is a large variation of depth in Lake Jempang. The deepest part of about six meters is found at a relatively small section in the middle area of the lake. A more uniform depth pattern is found in Lake Semayang and Melintang. Deeper section is found in the channel connectiong the two shallow lakes.

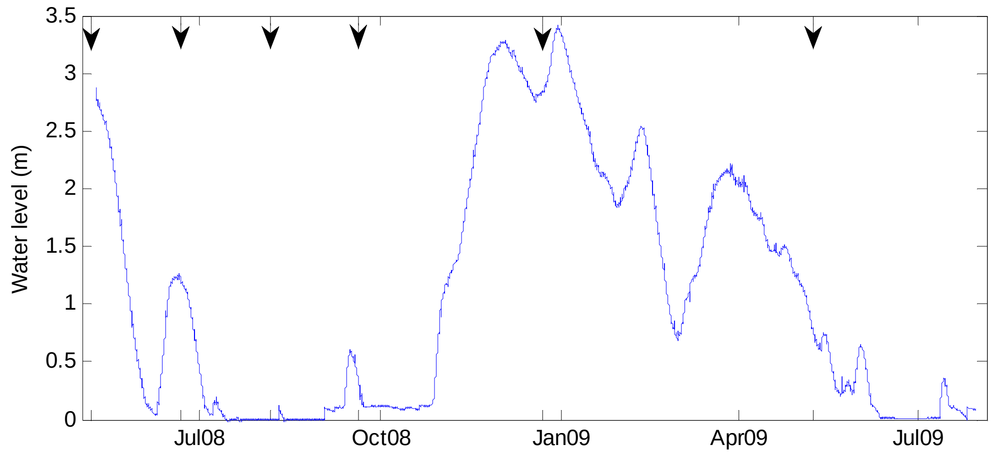

Fig. 3. Water level at Lake Jempang measured in Pulau Lanting village. Arrows indicate the PALSAR data acquisition date.

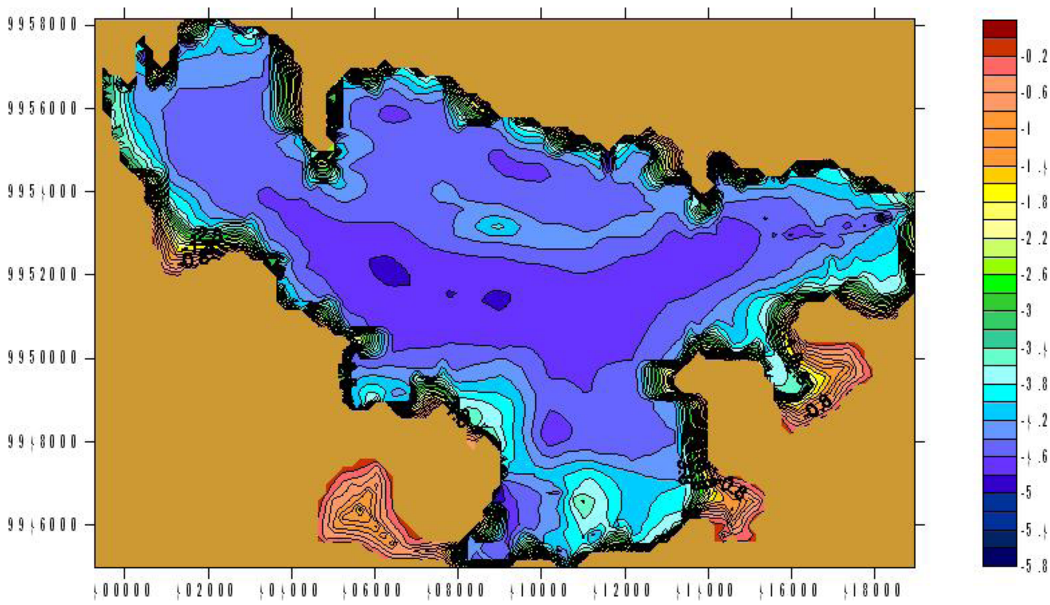

Fig. 4. Bathymetry of Lake Jempang interpolated from lake depth measurements in March 2009.

Image filtering

Image filtering (Fig. 6) was applied prior to flood frequency mapping. The filtered image showed a less noisy signals (Fig. 7). In a preliminary flood frequency map derived from unfiltered images, contours of the river and lake extent, which coincide with the circumferences of the areas with maximum flood frequency, was rather noisy (Fig. 8). The enhanced Lee filter that uses coefficients of variation within individual filter windows was used to reduce speckle in the radar images while preserving texture information.

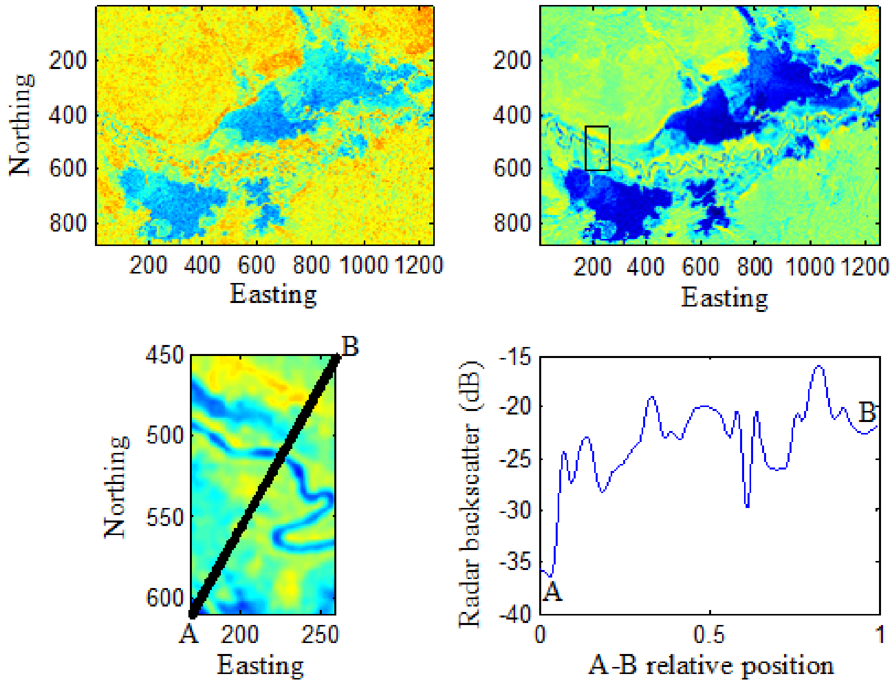

Fig. 5. Two-dimensional image filtering of PALSAR image of the Mahakam lakes area. The top left is the original image, top right is the filtered image. Lower left image show a part of the image section from the shore of Lake Jempang across the river up to the norhern floodplain in Penyinggahan and the corresponding radar backscatter shown in the lower right.

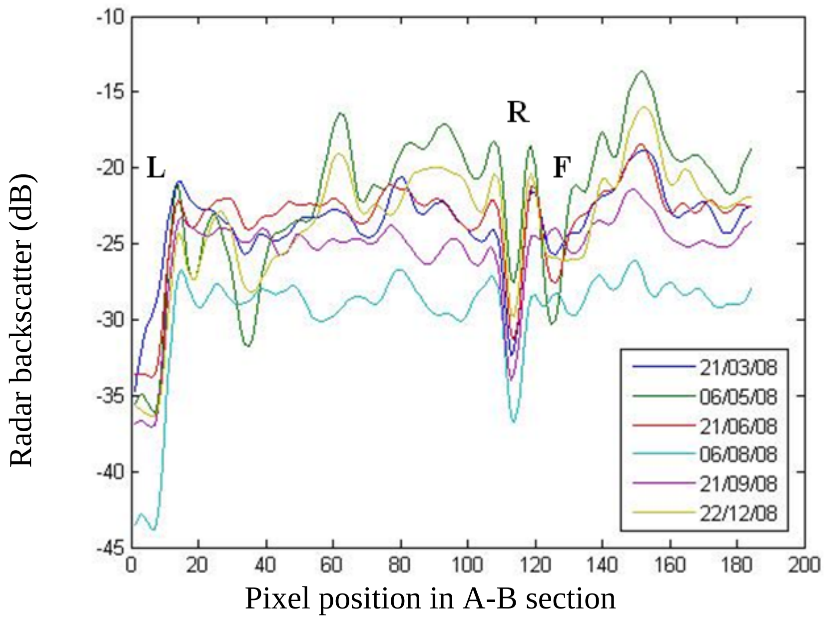

Fig 6. Backscatter value (dB) of filtered PALSAR images through floodplain (F) Mahakam river (R) and Lake Jempang (L) taken from the A-B sections in Fig. 6 in different image acquisition dates.

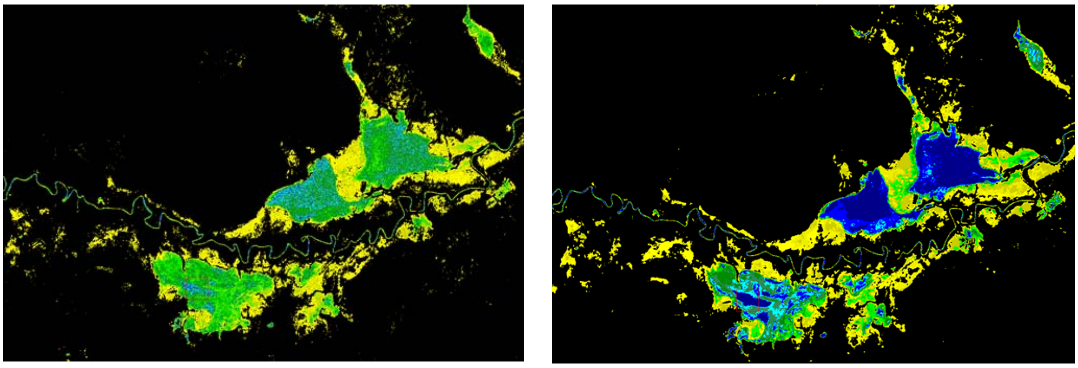

Fig 7. Colour map of flood frequency obtained from unfiltered 20 PALSAR images (left) and from filtered images using the enhanced Lee filter (right).

Principal Component Analysis

Principal component Analysis (PCA) of the radar imagery was carried out to detect areas where most changes of inundation occurred. By this means, the river floodplain and lake extension during the flooding period can be identified. PCA using three images during high water and three images during low water captured the water level dynamics. Applying the PCA training statistics to the whole image area and taking the first three output images as Red-Green-Blue (RGB) combination resulted in a clear pattern of lake inundation (Fig. 5). The figure shows that during peak flood, Lake Semayang and Lake Melintang are combined into a large lake and extended by the adjacent floodplain. Compared to Lake Semayang and Lake Melintang, Lake Jempang has the highest dynamics in terms of temporal inundation area. Only a small portion of Lake Jempang is inundated during the driest period of the PALSAR images acquisition dates.

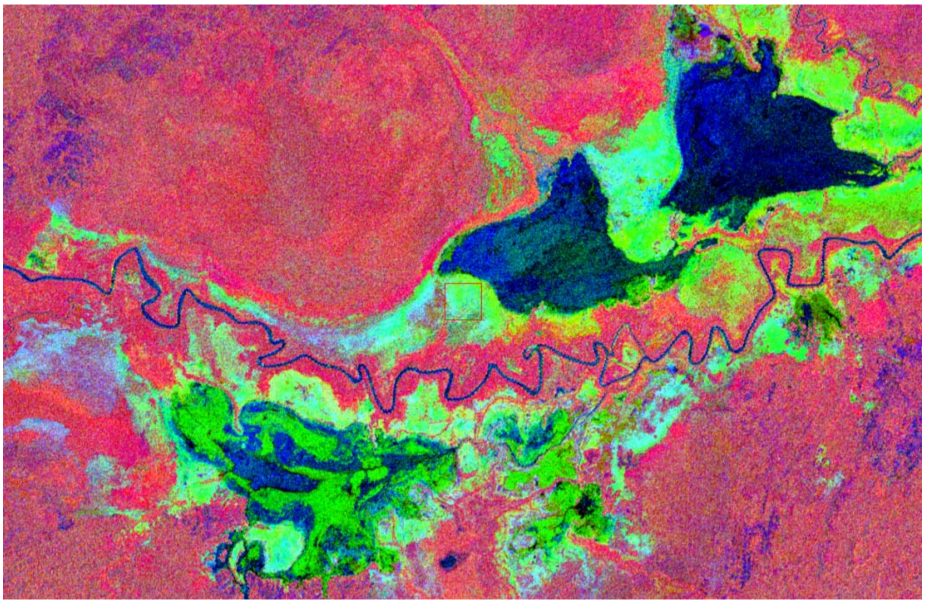

Fig. 8. RGB colour composite of the first three PCA output of PALSAR images of the Mahakam lakes area. Bright green indicates floodplain inundation/lake extension. Dark blue indicates permanently inundated area.

Frequency of inundation

A fully inundated region can be easily recognized on radar images from the dark signature. Figure 9 shows flood frequency map of Mahakam cascade lakes from 20 PALSAR images.The lake inundation frequency has quite similar pattern as the result of the analysis using PCA. The norhern lakes (Semayang and Melintang, on the one hand, have a more well-defined permanently inundated area. On the other hand, the southern lakes (Jempang and other smaller lakes) are more dynamics in terms of inundation extents. As shown in the bathymetry map (Fig. 4) large part of Lake Jempang is shallow and almost dry out during low water condition.In a rather speculative practice regarding lake inundation pattern, local farmers use the Mahakamlakes area, especially in Lake Jempang, for growing rice during the dry season. Apart from water from its catchment, Lake Jempang is largely filled by water from the Mahakam river through some small channels that to some extent maintain the high productivity of this lake. Rice growing is less suitable in Lake Melintang due to the low pH values of water generated from peat forest. Comparing the interpolated bathymetry and results of radar images analysis, we suspect that the relatively coarse resolution of lake depth measurement is not sufficient to acurately map the deep part of Lake Jempang. Bathymetry measurements with finer resolution is required to provide enough data points for a better interpolation results.

Nevertheless,this bathymetry data is useful for validation of flood occurrence map obtained from PALSAR images (Hidayat, 2012). This fact supports the argument of the compementary role of on-ground and remote sensing observations in the study area.

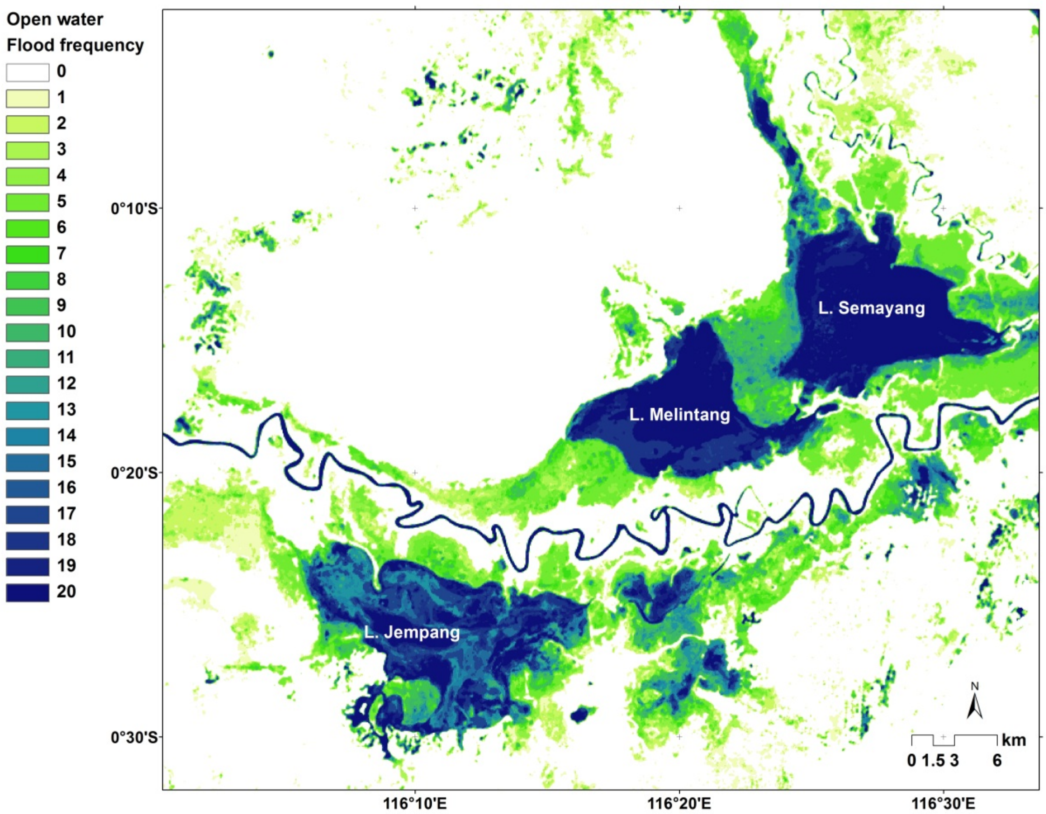

Fig. 9. Inundation frequency map of Mahakam cascade lakes from PALSAR images. The darkest colour indicates permanently inundated area.

CONCLUSIONS

Lake inundation extent and inundation frequency information can be extracted from radar images.A large variation of walter levels and lake inundation extent is revealed from on-ground measurements and analysis of satellite radar observations over the Mahakam lakes area. The inundation frequency map derived from satellite radar data gives insights into the dynamics of inundation extent and the water storage role of the area. The Mahakam cascade lakes along with other smaller lakes and the floodplain area provide a room for water storageduring high water period. The information on flood duration and inundation extent obtained in this study can be used in a future stage to model the hydrological functioning of the middle Mahakam area.

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