# Identification of Rainfall and Inundation Pattern Using Remotely Sensed Data in Lake Sentarum Floodplain Area

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**Abstract**

Wetlands are vulnerable natural habitats that should be preserved to protect habitat for fish and wildlife, flood mitigation, improve water quality, recharge area, and maintain surface water flow during dry periods. Water bodies and swamp areas are two primary components of the wetland. Considering its essential roles for the ecosystem, Lake Sentarum was set as a national park area (Lake Sentarum National Park – TNDS), Indonesia's 15 national priority lakes, and; designated as a Ramsar site (The Convention on Wetlands) in Indonesia. Despite the significant roles for the ecosystem, providing the limnological characteristic of Lake Sentarum remains a challenge due to its remote location. This study aims to identify the rainfall and inundation characteristics in the Lake Sentarum area and develop the rainfall-inundation relationship in the TNDS area. First, we carried out rainfall analysis using the Climate Forecast System Reanalysis (CFSR) data. Second, we utilized a remote-sensing-based global surface water map from the Joint Research Centre (JRC) to describe the historical inundation pattern. Third, we applied the Normalized Different Water Index (NDWI) combined with Modification Normalized Different Water Index (MNDWI) to the selected Landsat dataset to extract the inundation area. Finally, we developed a rainfall-inundation relationship in the TNDS area. The result indicated that the yearly rainfall in the TNDS area has an increasing trend, with the highest peak in December and the second peak in April. Historical Landsat data shows that the TNDS has a complex pattern of inundation. The maximum water extent was 649 $km^2$, with a 95 $km^2$ as permanent (90>- 100 % water occurrence). These areas were constantly flooded, even in the dry season. The most significant non-permanent water was 161 $km^2$ (80>- 90 % water occurrence). This permanent and larger temporary water area provides fish and other aquatic biotas habitats. It temporarily stores the water flowing slowly into the River Kapuas through the Tawang River. We captured the spatial inundation pattern and its relationship with the temporal regional rainfall. The developed relationship showed a lag of -60 days of accumulated rainfall correlated with the inundation area ($R^2$ of 0.48, n=11). These findings will thus provide valuable data for lake managers and policy-makers to protect the biota and habitat in Lake Sentarum National Park area.

Keywords: inundation pattern, Landsat, Lake Sentarum, rainfall pattern, remote sensing

## INTRODUCTION

Indonesia has 5,807 lakes with total area 586,871.64 Ha, consist of 1,022 natural lakes, 1,314 artificial lakes and 3,471 unidentified lakes (Dianto *et al,*. 2020a; Dianto *et al,*. 2020b; Dianto *et al,*. 2020c; Dianto *et al,*. 2020d; Dianto *et al,*. 2020e). Based on the forming types, Indonesian lakes can be classified into tectonic lakes, tectonic-volcanic lakes, volcanic lakes, crater lakes, caldera lakes, circumferential-caldera faults lakes, landslides lakes, oxbow lakes, and flood plain lakes (Lehmusluoto *et al.*, 1997).

Flood plain lakes are a natural water reservoir part of a river system in which the area and volume are directly affected by the river discharge. During the dry season, the water surface of the floodplain lake becomes narrow; remaining only the deep basin, main river, and oxbow lakes were inundated. During the rainy season, the water surface becomes very large;

almost all lake basins and river channels are flooded. This dynamic spatial and temporal water surface condition provides habitats for various aquatic organisms (Welcomme, 1985). The various habitats consist of lotic habitat in the river channel, lentic habitat in the swamp area, and lake habitat in permanent or semi-permanent lakes (Nanson & Croke,1992). This natural wetland habitat plays an essential role in the ecosystem, thus must be conserved (Williams, 1990).

Lake Sentarum is one of the large floodplain lakes in Indonesia, consisting of various size lakes, peat swamp forests, and freshwater swamps, with a maximum inundation area of about 1,000 $km^2$ (Hidayat et al., 2017). In 1999, the Lake Sentarum complex designated a national park called "Taman Nasional Danau Sentarum" (Lake Sentarum National Park, TNDS). A convention by UNESCO set the Lake Sentarum as a conservation area for sustainable wetland use (Ramsar site) in Indonesia (Giesen, 1996; Anshari et al., 2002, 2004). The Ramsar Convention is an agreement between member countries to commit to maintaining ecological processes of wetlands of international interest and strive to manage wetland areas in their territories wisely with the principle of sustainable use. In addition, in 2011, The Ministry of Environment of the Republic of Indonesia set Lake Sentarum as one of 15 national priority lakes. Those are lakes with the most urgent situation to determine effective management policies for sustainable use of lakes (MoE, 2011).

Common problems in TNDS are land conversion, changes in land use in the watershed, green belt disturbance, water pollution from anthropogenic activities, and overfishing (Ministry of the Environment of the Republic of Indonesia, 2011). Overfishing occurs mainly during the dry season in permanent puddles that should be protected as a shelter for aquatic animals during the dry season. In addition, the physical characteristic of Lake Sentarum remains a challenge to be studied due to its remote location.

Satellite remote sensing has been recognized as a supportive and powerful tool for collecting spatial and temporal earth surface data, especially for lakes located in remote areas. Several classification methods have been successfully used to identify inundations and water bodies using optical and radar imagery, such as visual interpretation, density slicing with multiband, multitemporal, and multisensory images (Frazier and page, 2000; Mishra and Chandra, 2015; Munyati, 2000; Chopra et al., 2001). Anersen et al. (2013) proposed monitoring the flooded area using ALOS ScanSAR. The lake water level could be detected using Landsat imageries (Reis and Yilmaz, 2008). Thus, remote sensing techniques can thus provide opportunities to delineate a dynamic water surface of a floodplain lake such as Lake Sentarum.

Therefore, the present study's objectives were to identify rainfall patterns, spatial and temporal characteristics of inundation in the TNDS area and provide essential information for the lake's sustainable use.

# METHODS

### Lake Sentarum and its watershed

Lake Sentarum National Park (TNDS) is in Kapuas Hulu Regency, West Kalimantan Province, Indonesia (between 111º55' - 112º26' E and 00º45' - 01º02' N). TNDS area lays on seven districts including Batang Lupar, Badau, Embau, Bunut Hilir, Suhaid, Selimbau and Semitau. Lake Sentarum act as a catchment area and a regulator of the water system of the Kapuas River (Figure1).

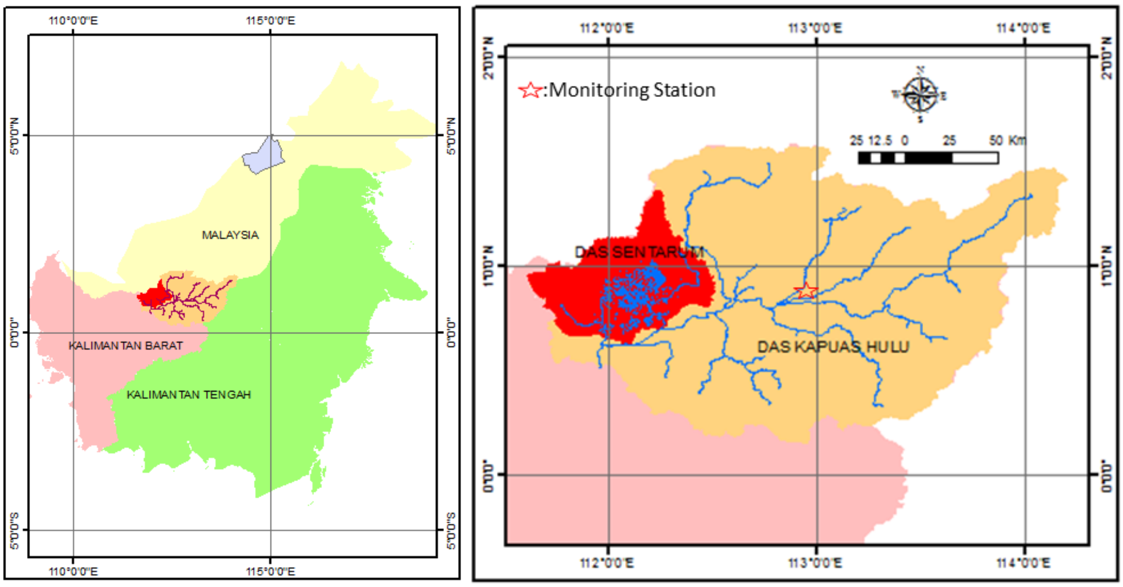



Figure 1. Location of Lake Sentarum situated in Lake Sentarum National Park-TNDS.

**Rainfall Data Collection and Analysis**

The first rainfall dataset from 1979 to 2013 was collected from Putusibau Monitoring Station (shown by a star symbol in Figure 1.). The second rainfall dataset was obtained from the Climate Forecast System Reanalysis (CFSR) at http://globalweather.tamu.edu. Compared with other data set, this data was relatively more detailed satellite-based data with a horizontal resolution of 38 km. This forecasting model is reinitialized every 6 hours with the global rain station data network of the World Meteorological Organization (WMO). This forecasting model has been widely used in Soil and Water Assessment Tools (SWAT) hydrological modeling (Fuka et al. 2013 and Saha et al., 2010). We perform monthly and yearly rainfall analyses to identify the rainfall characteristic of the study area. In addition, we calculated regional rainfall to perform precipitation-inundation area analysis.

**Surface Water Change**

We obtained the surface water transitions between the first year and the last year of observation from the Joint Research Centre Website (https://global-surface-water.appspot.com/download). This data portal provides free data access to Global Surface Water based on the research of Pekel et al. (2016). We use the boundaries of 0 – 10 N and 110 – 120 E to download the Global Surface Water data, including water occurrence change intensity, seasonality, recurrence, transitions, and maximum water extent. We then clipped using The TNDS area boundaries and performed the area calculation using GIS software.

**The Satellites and Spatial Data Collection**

We built the rainfall and inundation relationship using a separate Landsat Images dataset. A total of 11 Landsat images were downloaded from the USGS (United States Geological Survey) website. These satellite images include six images corresponding with the rainy season and five with the dry season (see Table 1 for details).

Table 1. Eleven Landsat 5 TM and 8 OLI images for rainfall and inundation analysis

| No. | Sensor | Acquisition Date | Season |
|---|---|---|---|
| 1. | 5 TM | April 25, 1991 | Rainy |
| 2. | 5 TM | July 30, 1991 | Dry |
| 3. | 5 TM | March 19, 2001 | Rainy |
| 4. | 5 TM | May 6, 2001 | Dry |
| 5. | 5 TM | July 31, 2009 | Dry |
| 6. | 5 TM | May 25, 2008 | Dry |

| No. | Sensor | Acquisition Date | Season |
|---|---|---|---|
| 7. | 5 TM | July 31,2009 | Dry |
| 8. | 8 OLI | November 7, 2010 | Rainy |
| 9. | 8 OLI | June 24, 2013 | Rainy |
| 10. | 8 OLI | April 24, 2014 | Rainy |
| 11. | 8 OLI | May 29, 2015 | Rainy |

**Data Processing**

**Automatic water delineation from Selected Landsat Imageries**

We identified the water pixel by using the combination of the Normalized Different Water Index (NDWI, [McFeeterss, 1996]) and the Modified Normalized Different Water Index (MNDWI, [Xu, 2006]). The NDWI and MNDWI values can be calculated using the following equations:

$$\mathbf{NDWI = (dgreen - dNIR)/(dgreen + dNIR),} \quad \mathbf{(1)}$$

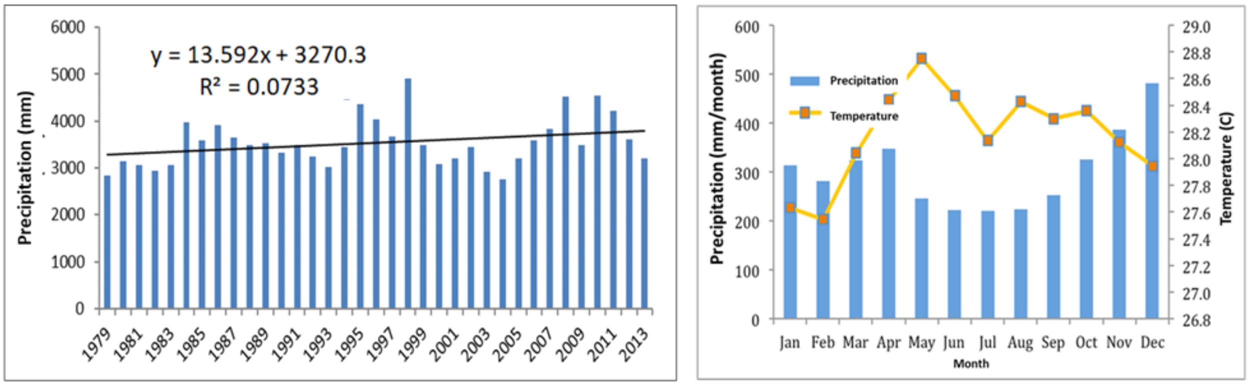
$$\mathbf{MNDWI = (dgreen - dSWIR)/(dgreen + dSWIR),} \quad \mathbf{(2)}$$

dgreen, dNIR, and dSWIR are the Digital Number (DN) values at the green band, near-infrared band, and shortwave infrared band. The non-water pixels were pixels with both NDWI and MNDWI values <0 within the lake polygons. Shadow from terrain and clouds can be misclassified as water (Pekel et al., 2016). However, as the study area has a flat terrain, the error from terrain shadow terrain can be negligible. In addition, cloud shadows were mitigated by selecting less cloudy images.

## RESULT AND DISCUSSION

**Rainfall characteristic**

Regional rainfall data analysis shows high yearly rainfall, from 2,760 - 4,909 mm/year, with an average of 3,535 mm/year. This result agrees with the study of Gunawan et al. (2013) at Putusibau Station. Figure 2.a. shows the annual and rainfall trend during 35 years. It was observed that rainfall in the region from year to year experienced various fluctuations but had an increasing trend (as shown by the positive slope in Figure 2. a). The oscillation is highly likely due to the influence of the El Nino and La Nina phenomena. Figure 2. b shows the monthly average rainfall pattern in the Lake Sentarum area. The highest average rainfall occurs in December (481 mm/month) and the lowest in July (219 mm/month).




(a) (b)

Figure 2. (a) Annual and the trend of rainfall (b). monthly average rainfall and temperature of Lake Sentarum area

**Maximum Water extent**

Figure 3 shows the spatial distribution of water and non-water extends in Lake Sentarum National Park. This map provides all locations ever mapped as water from the first acquired Landsat data in March 1984 to December 2020 (Pekel et al.,2016; EC JRC/Google, 2021). The result shows that the maximum water extends, non-water, and the total area of Lake Sentarum National Park is 649 km$^2$ (42,67%), 872 km2 (57.33%), 1,521 km$^2$, respectively.

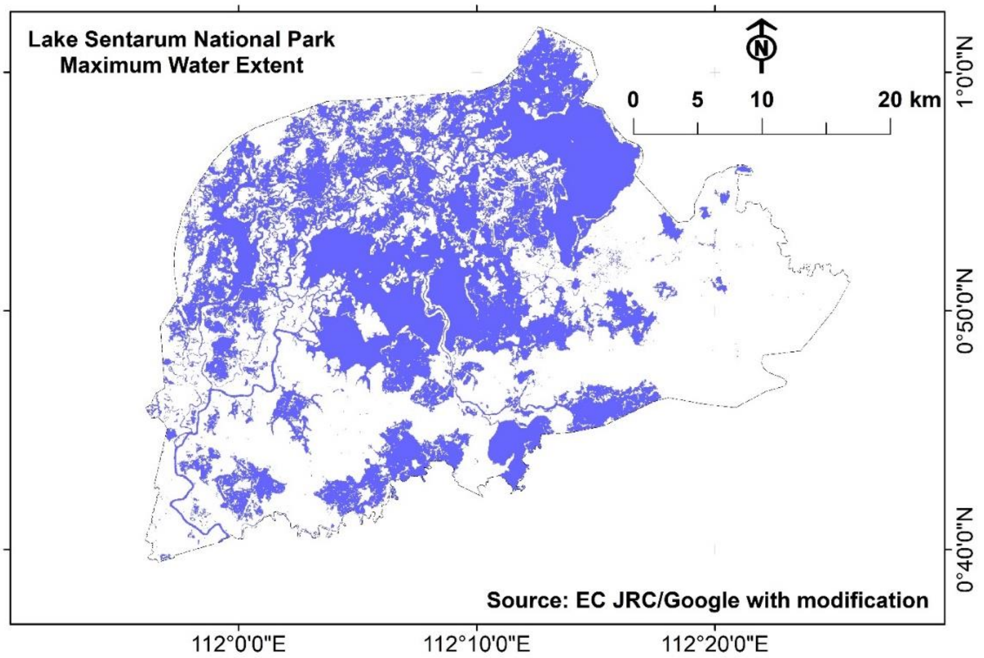



Figure 3. The maximum water extend of Lake Sentarum National Park

**Water occurrence**

The water occurrence map shows how often water was present on the surface of Lake Sentarum National Park during 36 years (1984 to 2020). The original data was range from 0 to 100 %. To simplify the map and area calculation, we reclassify them into ten classes with 10 percent intervals (Figure 4; see Table 2 for details). The area calculation results reveal that 95 $km^2$ has 90 -100 % records detected as water. The water occurrence was dominated by the 80 > - 90 % class, with an area of 161 $km^2$, followed by the 0> - 10 % class, with 110 $km^2$.

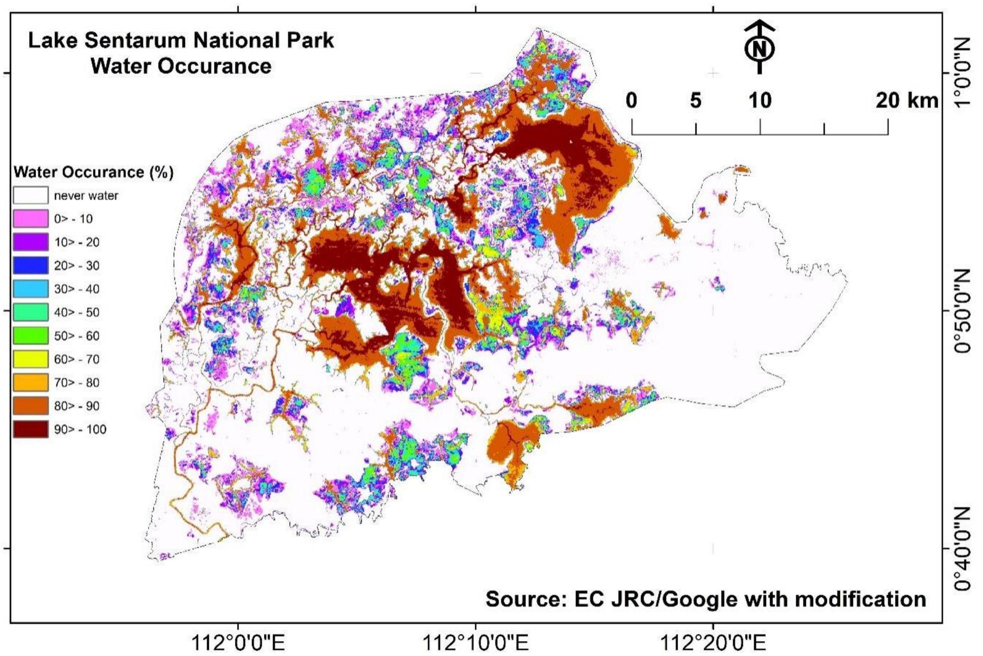



Figure 4. The Water Occurrence of Lake Sentarum National Park

Table 2. The Area of the Water Occurrence of Lake Sentarum National Park

| Water occurrence (%) | Area (km2) | Percentage of area (%) |
|---|---|---|
| Never water | 872 | 57.50 |
| 0> - 10 | 110 | 7.24 |
| 10> - 20 | 65 | 4.25 |
| 20> - 30 | 47 | 3.12 |
| 30> - 40 | 40 | 2.63 |
| 40> - 50 | 33 | 2.18 |
| 50> - 60 | 29 | 1.92 |
| 60> - 70 | 26 | 1.72 |
| 70> - 80 | 42 | 2.76 |
| 80> - 90 | 161 | 10.57 |
| 90> - 100 | 95 | 6.11 |
| **Total** | 1,521 | 100 |

**Water transition**

Capturing the change of water from the past to the recent year is essential for lake environment studies. Figure 5 shows how water changed from the data of the first year (1987) to last year (2020). The transition includes unchanging, permanent water surfaces; new permanent water surfaces (conversion of land into permanent water); lost permanent water surfaces (conversion of permanent water into land); unchanging seasonal water surfaces; new seasonal water surfaces (conversion of land into seasonal water); lost seasonal water surfaces (conversion of seasonal water into land); conversion of permanent water into seasonal water; and the conversion of seasonal water into permanent water. However, These conversions refer to changes in state from the beginning and end of the time series, and it doesn't represent the change in the intervening years (Pekel et al., 2016).

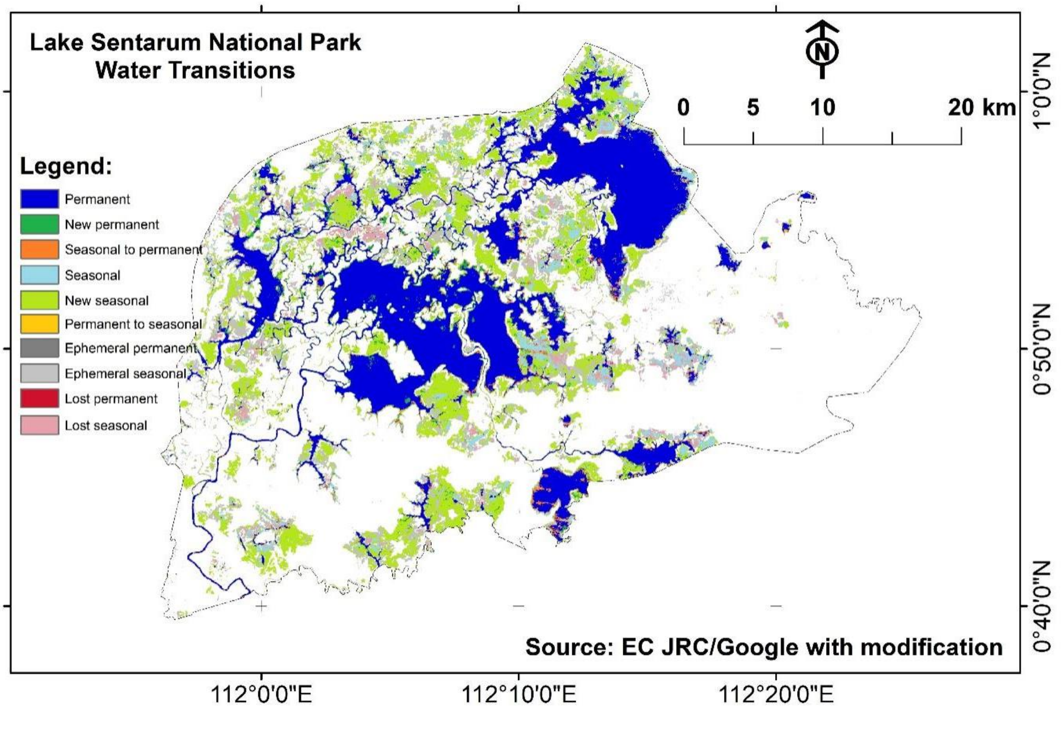



Figure 5. The Water Transition in Lake Sentarum National Park (first year to last year)

Table 3. The water transition in Lake Sentarum National Park (first year to last year)

| Water Transition | | Area ($km^2$) | Percentage (%) |
|---|---|---|---|
| **Permanent 293 $km^2$ 19 %** | permanent | 254 | 16.7 |
| | permanent from seasonal | 21 | 1.4 |
| | new permanent | 18 | 1.2 |
| | ephemeral permanent | 0 | 0.0 |
| **Seasonal 325 $km^2$ 21 %** | seasonal | 66 | 4.4 |
| | seasonal from permanent | 4 | 0.3 |
| | new seasonal | 177 | 11.6 |
| | ephemeral seasonal | 78 | 5.1 |
| **Lost Water 26 $km^2$ 2 %** | lost permanent | 0 | 0.0 |
| | lost seasonal | 26 | 1.7 |
| **Not water** | | 877 | 57.7 |
| **Total** | | **1,521 $km^2$** | **100 %** |

Table 3 shows that in the year 2020, 293 $km^2$ of Lake Sentarum National Park was detected as permanent water, 325 $km^2$ was detected as seasonal water, and 26 $km^2$ of seasonal water was converted into the land. Interestingly, 18 $km^2$ of land was converted into permanent water, and 177 $km^2$ land was transformed into seasonal water. Hidayat et al. (2020) mentioned that the Lake Sentarum National Park Area is a floodplain lake with a flood pulse driven by the hydrological factors upstream of the River Kapuas catchment.

**Rainfall and inundation relationship**

We build the inundation area obtained from the separate Landsat data (Figure 7) with the rainfall data obtained from CFSR using the Sentarum Watershed Area Rainfall. The results of the comparison are presented in Table 4. Regional Rainfall was calculated in periods of -10, -30, -60, and -90 days from the Landsat acquisition date to observe its impact on the lake inundation area. In general, the results show the relationship between the amount of regional rainfall and the inundation area, except for the LANDSAT image data on July 9, 2001, which shows different things where the inundation area of the lake is quite wide (274.6 $km^2$). However, the areal rainfall in the three periods is minimal; this was probably related to the more extended period of rain as seen in the previous inundation area (May 6, 2001), which remains and is released slowly into the River Kapuas through the River Tawang.

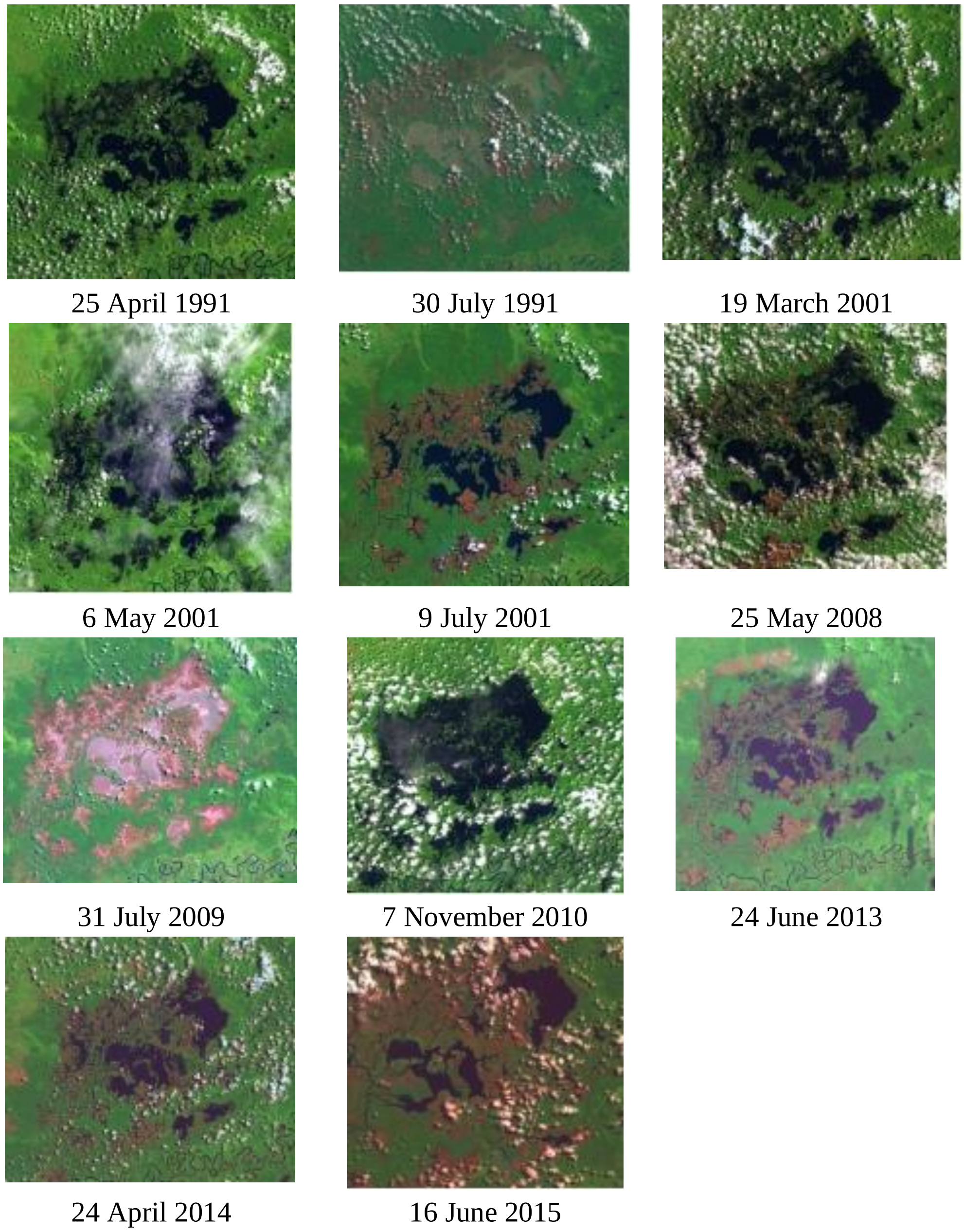



Figure 6. A "True Colour" version of LANDSAT in Wet and Dry season of Lake Sentarum National Park.

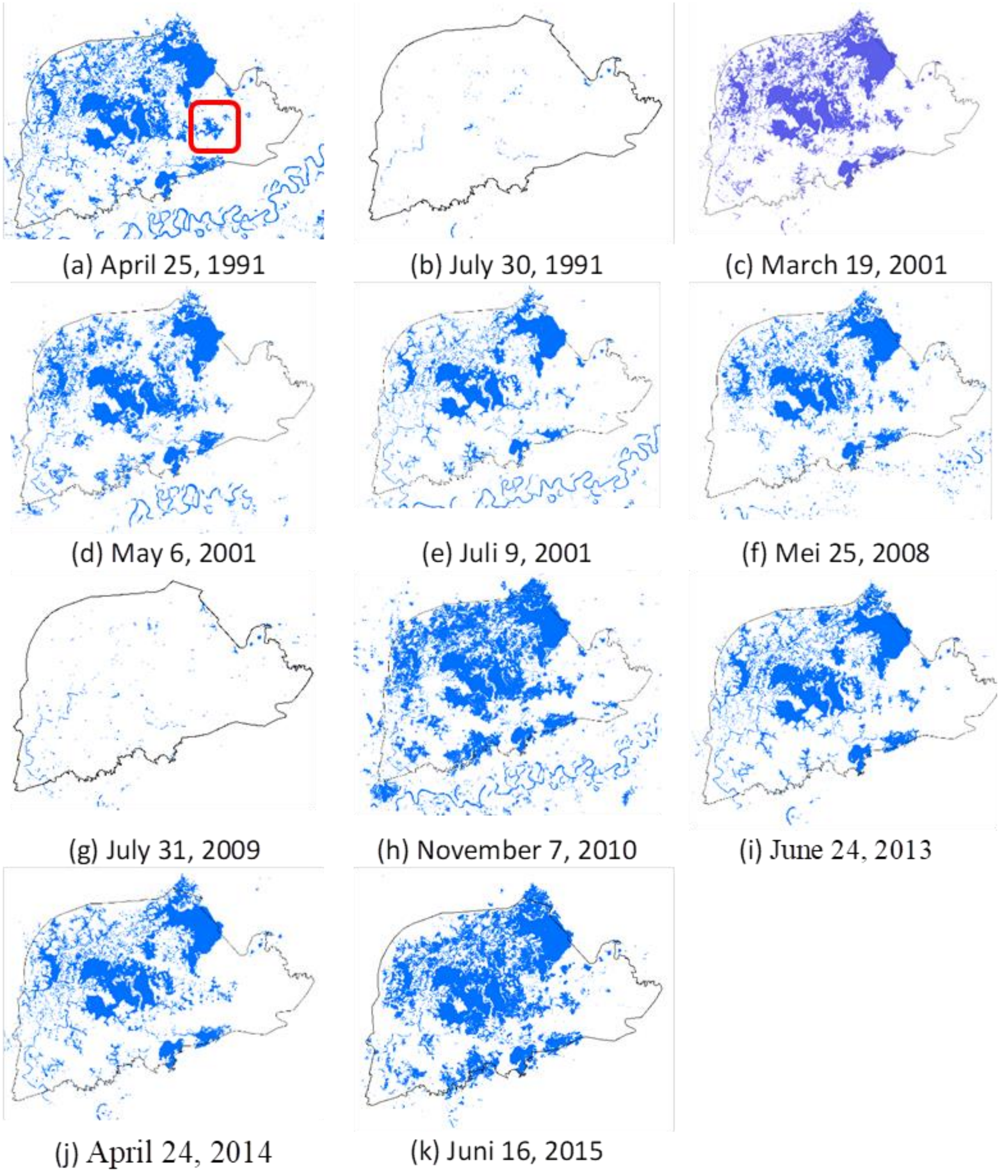



Figure 7. During the rainy and dry season, a contrast of water surface area was detected from Landsat images using two water indices, NDWI and MNDWI, in Lake Sentarum National Park.

Figure 6 shows the true color images, while Figure 7 is the water index classification result. They are showing several locations that remain inundated in the dry season, i.e., the Lake Meliau complex (red box in Figure 7.a.) and lakes along the River Tawang. We suggest designating this permanent water as the area of conservation in line with the native tribe ("*Suku Iban"*) local wisdom. They set lakes in their territory for fish conservation (Ridwansyah, 2014).

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Tabel 4. Landsat-based Inundation area and areal Rainfall in Lake Sentarum Area

| No | **Acquisition Date** | Inundation area ($km^2$) | ∑ Rainfall (mm) | | | | |
|---|---|---|---|---|---|---|---|
| | | | -10 days | -30 days | - 60 days | -90 days | Yearly |
| 1 | 25 April 1991 | 376.91 | 140.1 | 516.4 | 823.2 | 1037.8 | 3489.4 |
| 2 | 30 July 1991 | 6.78 | 25.5 | 188.1 | 484.5 | 906.6 | |
| 3 | 19 March 2001 | 384.65 | 71.5 | 312.2 | 799.8 | 1134.8 | |
| 4 | 6 May 2001 | 373.75 | 104.8 | 320.3 | 683.3 | 1050.6 | 3208.1 |
| 5 | 9 July 2001 | 274.56 | 0.1 | 51.2 | 296.0 | 563.7 | |
| 6 | 25 May 2008 | 327.5 | 35.9 | 212.2 | 536.9 | 1152.4 | 4530.0 |
| 7 | 3 Juliy 2009 | 15.6 | 92.1 | 154.7 | 321.2 | 658.8 | 3483.6 |
| 8 | 7 Nov 2010 | 551.98 | 175.6 | 446.8 | 857.9 | 1317.4 | 4539.8 |
| 9 | 24 June 2013 | 335.03 | 0.09 | 101.4 | 399.2 | 727.2 | 3198.5 |
| 10 | 24 April 2014 | 328.31 | 207.3 | 429.1 | 655.0 | 703.9 | - |
| 11 | 16 June 2015 | 486.09 | n.d | n.d | n.d | n.d | n.d |

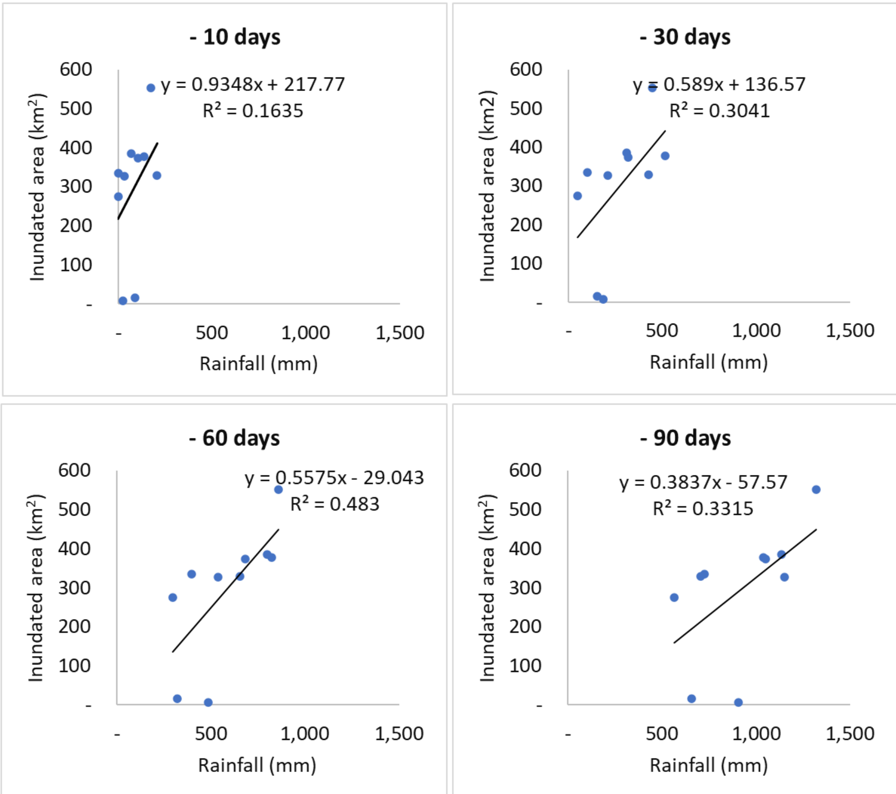


Figure 8. Relationship between accumulated rainfall and the Landsat based inundation area in Lake Sentarum National Park

## CONCLUSION

We identified an increasing yearly rainfall and a complex inundation pattern, including permanent and non-permanent water in Lake Sentarum National Park (TNDS). The developed relationship of the rainfall-inundation area initially informed the role of TNDS to support the aquatic ecosystem and store water (for at least two up to three months) as a part of the River Kapuas system. Further, the rainfall-inundation pattern and its relationship provide primary biota and habitat protection management information.

## SUGGESTIONS

Higher frequency data is necessary to obtain a better Rainfall-inundation relationship. We suggest using radar imageries that are not dependent on cloud cover, combined with water level and rain gauge network covering Lake Sentarum Watershed. Thus dynamic inundation patterns can be constructed using hydrodynamic models.

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## DECLARATION

Iwan Ridwansyah and Fajar Setiawan is the main contributior of this manuscript.

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