

Original Research Article**Vegetation Impact on the Morphodynamic Activity of the River Kapuas****ABSTRACT**

Aims: To understand the causes behind the spatial variability of the morphodynamic activity of the river Kapuas, West Kalimantan, Indonesia.

Study design: This study was designed to focus on the vegetation impact on the morphodynamic activity of the river Kapuas based on the Normalized Difference Vegetation Index (NDVI) using Landsat images.

Place and Duration of study: Hydrology and Quantitative Water Management Group of Wageningen University and Research Centre, The Netherlands between September 2013 to March 2014.

Methodology: Landsat images from 1991 to 2013 were used to interpret the vegetation impact based on NDVI values. At first land cover of the entire river corridor was classified based on unsupervised classification system and then NDVI map of the same area was plotted using ENVI4.8. From the land cover classifications, NDVI maps and some videos, captured from the study area using hand GPS, vegetation types and corresponding NDVI values were detected.

Results: High NDVI values usually indicate vegetation of high biomass both above and below the ground. Vegetation reinforces the soil particle and holds the soil particle in position against erosion. This research show that banks with little vegetation, having NDVI values of 0.45 or less, are morphologically more active than banks with dense vegetation, having NDVI values over 0.45.

Conclusion: Vegetation has significant impact on the morphodynamic activity of the river Kapuas. Vegetation of high NDVI values give comparatively more stable bank against erosion than the vegetation of lower NDVI values, especially below 0.45

Keywords: Bank protection, Bank Migration, Erosion, Morphodynamic activity, NDVI, Vegetation

1. INTRODUCTION

River morphology describes the changes of the planform and shape of a river channel over time in relation to its floodplain. The morphology of a river channel is a function of a number of processes and environmental conditions. Vegetation is the most important environmental element that plays a role in morphodynamic variability along the river corridor. Effects of vegetation on the morphodynamic variability of the river depend on the vegetation types, age, health and density (Corenblit et al. 2007; Perucca et al. 2007; Perucca et al. 2006). Vegetation has a strong influence on the bank erosion rate in small rivers and streams, especially for adding shear strength (Wharton 2004). Soil is strong in compression but weak in tension and vegetation roots show reverse property. Plant roots provide mechanical reinforcement to the soil matrix by different responses of soils and roots (Prandini et al. 1977) that hold soil particles strongly within its root zone (Abernethy & Rutherford 1998). This reinforcement increases bank stability by increasing shear strength (Abernethy & Rutherford 1998). Millar (2000b) found that vegetation with well-developed root networks have a critical shear strength three times higher than the weak vegetated or grassland banks. Larger rooting depth and rooting density shows high bank stabilizing capacity by leading low lateral mobility of bank materials, which results in narrow and deep channel (Davies-Colley 1997). Bank vegetation results in narrower channel with a high erosion resistance (Gran & Paola 2001), because it increases the frictional angle value which exerts quantifiable and significant control on alluvial channel patterns. Huang & Nanson (1997) argue that dense vegetation narrows the channel width and resist to widening the channel.

Perucca et al. (2007) concludes, vegetation has influence on meander evolution. However, Vegetation also has some effect on bank destabilization (Simon & Collison 2002). There is a hypothesis that vegetation improves soil structures by rooting and litter production that promotes biological activity. This biological activity creates meso and macro pores which enhance infiltration capacity leading to destabilizing the banks (Mamo & Bubenzer 2001). Vegetation growing on channel bed cause flow resistance, wide channel, reduce flow velocity but no significant change in depth (Huang & Nanson 1997). It also influences flow dynamics by increasing the variance of flow direction in vegetated runs and increasing scour depths through strong down welling where the flow collides with relatively resistant banks (Gran & Paola 2001).

West Kalimantan is one of the four Indonesian provinces in Kalimantan, the Indonesian part of the island of Borneo. The Kapuas is a river in Indonesian part of Borneo islands, at the geographic centre of Maritime Southeast Asia. It is the longest river of Indonesia, draining the central mountain range of Kalimantan and one of the longest island rivers of the world. The Kapuas is about 1143 km in length and has widths up to 400 m, embedded in alluvial floodplains. The upper and the middle reach of the Kapuas flows through dense tropical forest most of which are in accessible. Through the entire length of the Kapuas, about 210.0 km (along the centre line) in the upstream of the Kapuas lake area is found to be morphologically very active (Huisman 2014).

Over the past decades, tropical rivers have attracted attention of researchers from different research points of view. Latrubesse et al. (2005) summarize these topics and state that the knowledge is still limited due to the large inaccessible size of the tropical rivers and large extents of land surfaces that are indicated as the tropical region. Latrubesse et al. (2005) also conclude lack of knowledge exists about morphological and sedimentary processes of tropical rivers. According to Gupta et al. (2002) most of the knowledge on geomorphic processes has been gained from small rivers that may differ from large river systems. Regarding large rivers, the planform of tropical rivers are less studied as compared to their counter parts in temperate climate zones (Gilvear et al. 2000). As a tropical river, the Kapuas also has attracted the attention of many researchers but the causes of morphodynamic variability in different reaches are not well-understood yet. According to Huisman (2014), the upstream part of the river Kapuas is more active than the downstream part and the bank migration rate is 1.80 m and 0.90 m per year in the upstream and downstream area, respectively. High rate of morphological change, heterogeneous landscape and environmental conditions attracted to study on morphodynamic variability of the world's longest river on an island: the Kapuas in West Kalimantan, Indonesia.

2. MATERIALS AND METHODS

Delineation of river banks of different time series is a prerequisite for understanding morphological dynamics of a river. This research used delineated river banks from a previous research by Huisman (2014) who delineated a series of river banks from 1973 to 2013 and quantified the bank migration rates along the reaches of Kapuas. Some morphological units, at or around the river bends where the migration rates were found significant, were selected to investigate the vegetation impact and the steps followed afterwards are shown in the Figure 1.

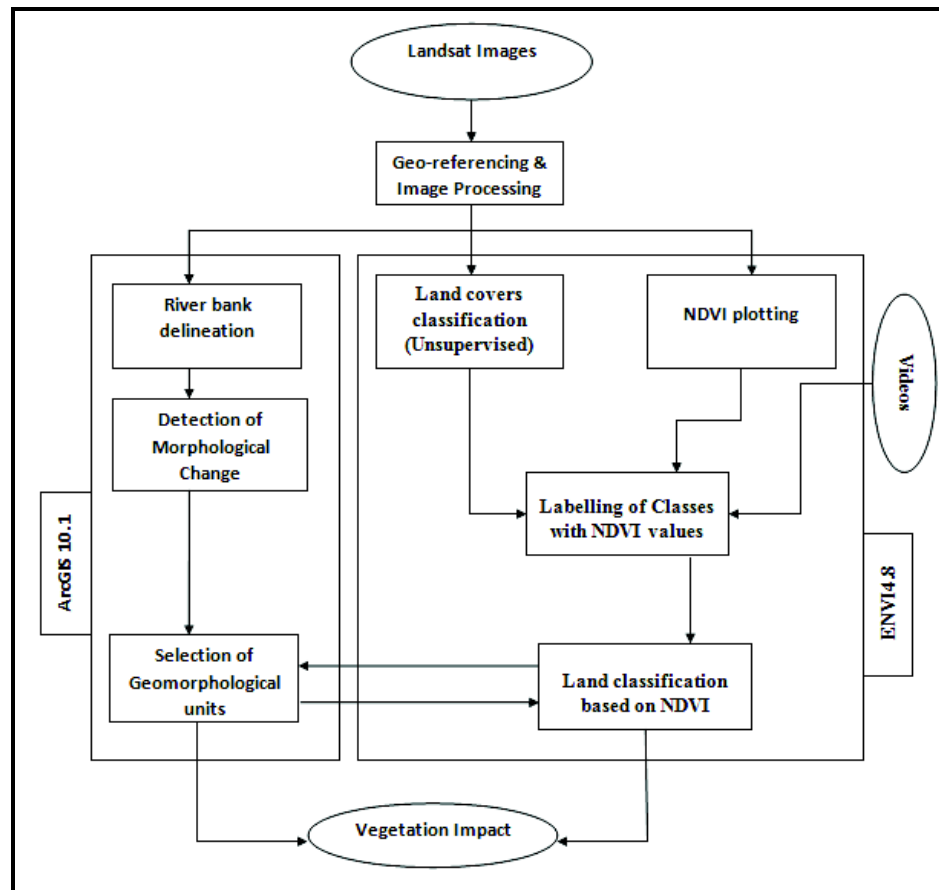


Figure 1 : Methodological flowchart of the investigation of vegetation impact

2.1 LAND COVER CLASSIFICATION

An unsupervised classification technique was used in this study due to unavailability of a training site or polygons of land cover in the study area. For unsupervised classification and calculating NDVI, ENVI 4.8 was used as an operating tool. K-means classification with 16 classes and 16 iterations were used to classify the land cover around the banks of the entire length of Kapuas (Figure 2) as K-means classification is suitable for identifying seven relatively separable classes like water, rough pasture, bare soil/urban area, wood land, grass land, arable land and cloud/quarry/industrial area. However, in the K-means classification system, it is really difficult to interpret which land cover types fall within which category. Within the same image, the same land cover type shows the same category, but in case of different images or in the images of different time series it may be or may not be the same. In this study, the Landsat images of 1973, 1991, 1995, 1994, 2001, 2004, 2005 and 2013 were used to classify (in an unsupervised manner) the land covers of the whole area around the entire length of Kapuas.

For identification of land cover types in this study fifty two geo-referenced videos (captured while standing at a specific point and using handheld GPS) with their geographical coordinates in the upstream part of the study area were used. Videos around a specific point can give an idea of types of that area. Then from the unsupervised classification types and reflectance profile of the area it can be deduced which land cover types are belonging to which classified category. Based on the classification category, reflectance profile and videos, vegetation types corresponding to an

unsupervised classification category were selected. Then NDVI values of the selected categories were used as a unique tool to identify the vegetation and land cover types within the study area.

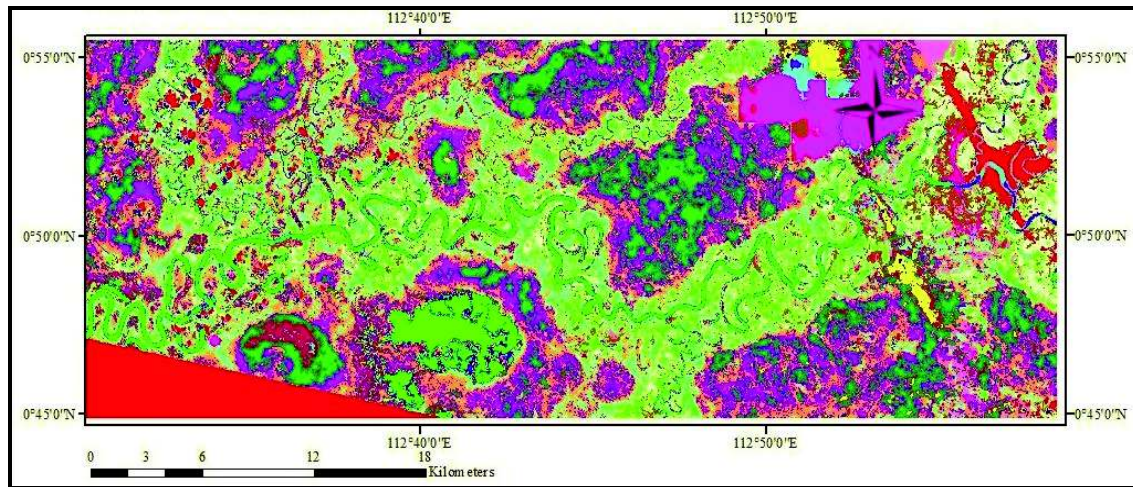


Figure 2 : Land cover classification of the upper upstream area of Kapuas

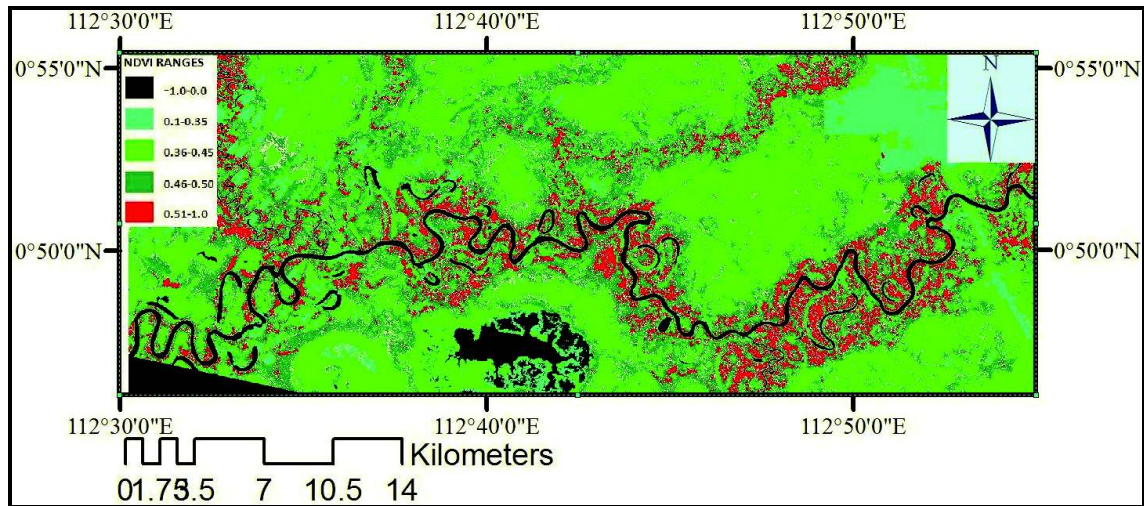
2.2 NDVI CALCULATION

To calculate the NDVI values of the entire Kapuas area images of Landsat 5 (1991, 1995, 1994 and 2005), Landsat 7 (2001) and Landsat 8 (2013) were used in this study. Smaller pixel values usually give a better result for land cover investigation and to avoid the effect of soil moisture and water on leaves images of dry periods were used only. With the band math calculation in ENVI4.8, the NDVI values of the whole study area were plotted by using the following equation.

$$NDVI = \frac{NIR - VIS}{NIR + VIS}$$

Where VIS and NIR stand for spectral reflectance measurement acquired in the visible (red) and near-infrared regions, respectively. NDVI values vary between -1 and 1. The values from -1 to 0 indicate vegetation free surface, like bare soil, and water bodies, and they were grouped together as a value of 0. Around the Kapuas, the whole study area is covered by more or less vegetation except for the water bodies, open crop field and urban area. NDVI values of the whole study area were plotted between the year 1991 and 2013 and the ranges of values were regrouped into different colour codes (Figure 3). One pixel area (30 m x 30 m) represents one NDVI value, but within this pixel area the NDVI values may be different. To get a view of different NDVI values within the pixels, the contour lines of the same NDVI value were plotted that helped to identify land cover types of the same vegetation even in one pixel. In case of the same NDVI values for different land cover types (from the unsupervised classification) or the other way around, the spectral profiles of middle infrared bands were used to separate the land covers as well as vegetation types. NDVI values corresponding to vegetation types (Figure 4) clearly show that, with increasing vegetation density and biomass, the NDVI values are increasing. Beyond a certain range, NDVI becomes saturated for higher biomass. Box et al. (1989) suggest a saturation NDVI value of 0.40 and 0.54 was suggested by Santin-Janin et al. (2009) for saturation in case of higher biomass. In this study NDVI values larger than 0.45 are found for the vegetated area with comparatively higher biomass and more than 0.50 shows saturation of the NDVI.

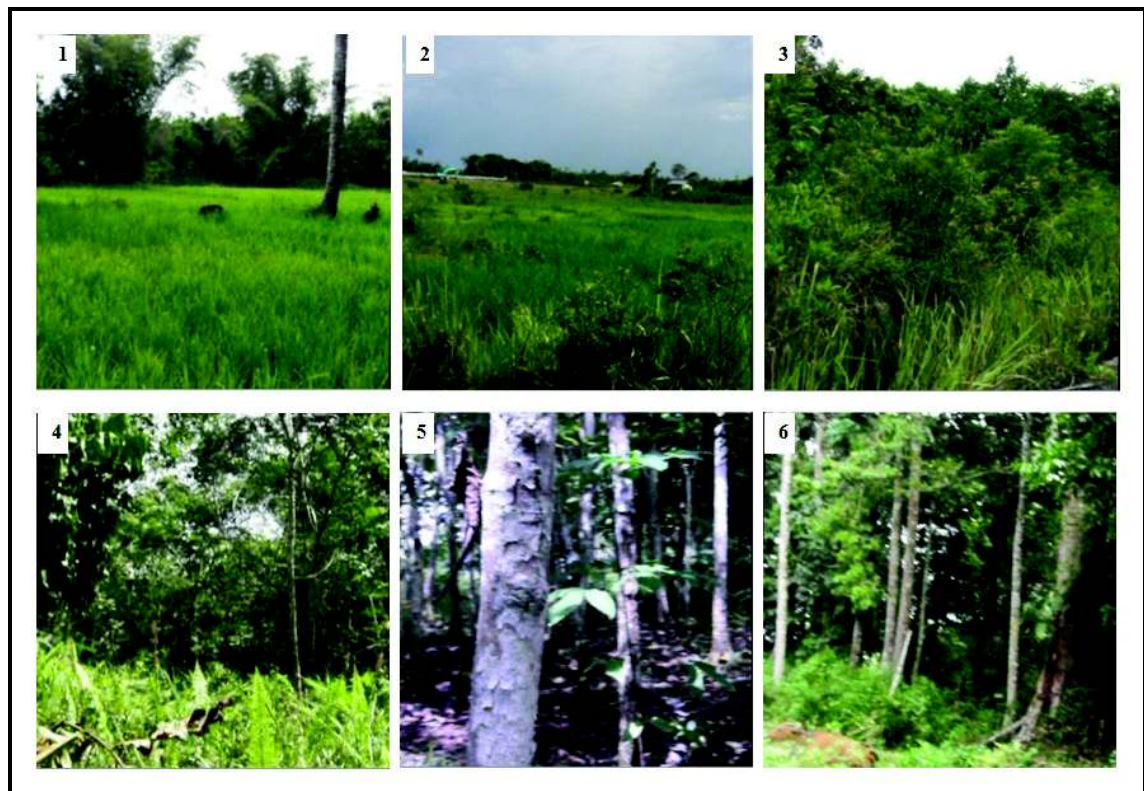
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Figure 3 NDVI map of the upper upstream of Kapuas River, 2013



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Figure 4 : Vegetation types and their corresponding increase in NDVI values. Land cover type 1 & 2 showing NDVI values 0.33-0.38; 3 & 4 showing NDVI values 0.40-0.45 and 5 & 6 showing values 0.48 and more

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3. RESULT AND DISCUSSION

Landsat images of 1991, 1994, 1995, 2001, 2004, 2005 and 2013 were used to investigate vegetation influences on morphological dynamics. NDVI was used as a unique tool to identify the vegetation type and vegetated land covers. Throughout the entire length (upstream), both banks of the Kapuas were found more or less vegetated but of different vegetation types. Within the study area (upstream) along the entire banks it is found that, river banks with NDVI values of 0.45 or less are eroded and banks with NDVI values more than 0.45 are not eroded or almost stable. It means that the river is migrated at low biomass vegetated areas but not at high biomass vegetated areas, as high NDVI value represents vegetation of high biomass both above and below the ground. Trees reinforce the soil particles within its root zone and hold soil particles in position against erosion. A higher NDVI value is an indicator of a highly vegetated area with high aboveground biomass (Boelman et al. 2003; Santin-Janin et al. 2009) and aboveground biomass is positively correlated with the plant biomass below ground (Cairns et al. 1997). The size, depth and distribution of biomass below the ground, roots of trees, increases with the increase of size and life span of trees above ground (Schenk & Jackson 2002), which increases the soil shear strength (Millar 2000b) to protect from erosion. The pictures of the vegetation types (Figure 4) with NDVI values confirm that high NDVI values can be considered as high biomass above ground. The migrated banks are found to have NDVI values around 0.36-0.43, but not more than 0.45 whereas the area around the bends, which are not migrated or almost stable, are found to have NDVI values of 0.45 or more.

However, this study didn't deal with the soil types and the interaction between the vegetation roots and soil particles. This study used only one vegetation index NDVI and a pixel of Landsat image covers 30 m x 30 m ground area and represents one NDVI value. To protect the banks from erosion by increasing soil shear strengths by root reinforcement, the river banks should not have always vegetated area of 30 m x 30 m. Vegetation on the banks, which may not be visible in Landsat images due to not covering the whole pixel, can also give good protection from the erosion process that is already observed from field work at stable banks (Huisman 2014). In this case, contour lines of the same NDVI value that passes through the pixels ensure differences in vegetation even in one pixel. On the contrary, dense shrubs can also give a high NDVI value but their root zone may not penetrate such depth to protect toe erosion or mass failure. It is also true that the root biomass distribution of all species of vegetation is not the same (Jaramillo et al. 2003) but they can have similar canopy structure which may give the same NDVI. For instance, primary tropical forest and secondary tropical forest may have similar canopy structure and may result in the same NDVI values, but their root biomass distribution below ground might be different as they have different biomass above ground (Schenk & Jackson 2002). In case of the same NDVI values with different land cover classes, the middle infrared band is used to differentiate the vegetation types as it is sensitive to biomass and maturity of the vegetation (Foody et al. 2001).

Moreover, some vegetation species may have root distribution much higher in the horizontal direction rather than vertical direction under the ground or the other way around. In that case the banks stability by vegetation would be different regarding strength provided by root reinforcement. The depth of the river and variation of the water level also play a role on morphodynamic activity. For instance, in presence of bank vegetation, if the water level of the river falls down and stream flows below the root zone of vegetation, the banks of loose soils can be eroded at toe level due to excess shear stress, generated from high flow velocity. In this case, from the Landsat images bank vegetation can have high NDVI values, but that vegetation may not be able to protect the banks as their roots are not penetrated to such depth like crops and shrubs (Millar 2000b).

Though Kapuas is the longest tropical river in Indonesia but it has not depth that much and during the wet season its water level comes up causing flash floods over the banks (Mackinnon 1996). As maximum bank erosion and migration occurs during the peak discharge (Julian & Torres 2006) and

Kapuas banks overflow during the peaks (Mackinnon 1996) vegetation might play a role in the morphodynamic activity as it increases soil shear strength, gives bank stability and resists river bank widening (Millar 2000a; Huang & Nanson 1997). In this study the impact of vegetation was focused mainly around the bends instead of straight rivers as maximum bank migration occurs around the bends (Keijzer 2012) that makes the river morphologically more active. A high NDVI value indicates high vegetation biomass both above and below the ground (Santin-Janin et al. 2009; Boelman et al. 2003; Cairns et al. 1997). Consequently vegetation of high NDVI will give comparatively high bank stability by dense root networks under the ground and have influence on bank migration as well as morphodynamic activity and it is valid for the rivers which have depths as much as Kapuas.

4. CONCLUSION

The objective of this study was to understand the vegetation impact on the morphodynamic activity of the river Kapuas. To address the objective, Landsat image from 1973 to 2013 were used to plot NDVI map of the study area and NDVI was used as a unique tool to identify the vegetation types and their corresponding biomass. From the results this study concludes that vegetation has significant impact on the morphodynamic activity of the river based on their health, density and biomass both above and below the ground. In terms of NDVI it also concludes, river banks with little vegetation, having NDVI values of 0.45 or less, are morphologically more active than banks with dense vegetation, having NDVI values over 0.45.

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