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Vegetation Impact on the Morphodynamic Activity of the River Kapuas

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Authors' contributions

This work was carried out in collaboration between all authors. Author MMH designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript and managed literature searches. Authors MMH, AJFH and JC managed the analyses of the study and literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: To have the clear understanding of 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 an

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unsupervised classification system and then NDVI map of the same area was plotted using ENVI4.8. Based on the land cover classifications, NDVI maps and some videos, captured from the study area using handheld 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 shows that banks with a little vegetation having NDVI values of 0.45 or less are morphologically more active than the banks with dense vegetation having NDVI values over 0.45.

Conclusion: Vegetation has a positive impact on the morphodynamic activity of the river Kapuas. Vegetation with high NDVI values give comparatively more stable bank against erosion compared to vegetation with 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. Among these vegetation is one of the most important environmental elements that play 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 [1-3]. Vegetation has a strong influence on the bank erosion rate in small rivers and streams, especially for an added shear strength [4]. 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 [5] that hold soil particles strongly within its root zone [6]. This reinforcement increases bank stability by increasing shear strength [6]. Millar [7] found that vegetation with well-developed root networks has critical shear strength three times higher than the weakly vegetated or grassland banks. A larger rooting depth and rooting density show high bank stabilizing capacity by leading to a low lateral mobility of bank materials which in turns results in a narrow and deep channel [8]. Bank vegetation results in a narrower channel with a high erosion resistance [9], because it increases the frictional angle value which exerts a quantifiable and significant control on alluvial channel patterns. Huang & Nanson [10] argued that a dense vegetation narrows the channel width and resists widening of the channel. Perucca et al. [11] concluded that vegetation has an influence on meander evolution. However, vegetation also has some effects on bank destabilization [12]. There is a hypothesis that vegetation improves soil structures through rooting and producing litter that promotes biological activity. This biological activity creates meso and macro pores which enhance infiltration capacity leading to destabilization of the banks [13]. Vegetation growing on a channel bed causes flow resistance, widens channel, reduces flow velocity without causing any significant change in depth [10]. It also influences flow dynamics by increasing the variance of flow direction in vegetated runs and increases scour depths through strong down welling where the flow collides with a relatively resistant banks [9].

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 width up to 400 m, embedded in alluvial floodplains of three soil types; Dystric Histosols (Od), Humic Gleysols (Gh) and Dystric Fluvisols (Jd). The upper and the middle reach of the Kapuas flows through a dense a tropical forest most of which is inaccessible. Throughout 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 [14] which lies in between two points, 0051'11.6" N, 112057' 8" E and 0038' 11.47 " N, 111059' 3.95 " E. The study area starts from Putussibau and ends at the most downstream point, very close to the sea and it possesses heterogeneous land cover with climatological variability, various environmental conditions and variable hydrological processes and river discharge.

Over the past decades, tropical rivers have attracted much attention of researchers from different research viewpoints. Latrubesse et al. [15] summarized these topics and stated that the knowledge is still limited due to a large inaccessible size of the tropical rivers and large extents of land surfaces that are indicative of tropical region. Latrubesse et al. [15] also concluded that a lack of knowledge that still exists about morphological and sedimentary processes of tropical rivers. According to Gupta et al. [16] the 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 is not well studied as compared to their counterparts in temperate climate zones [17]. As a tropical river, the Kapuas also has garnered the attention of many researchers but the causes of morphodynamic variation in different reaches are not well-understood yet. According to Huisman [14] 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. A high rate of morphological changes, heterogeneous landscapes and environmental conditions are too impressive and interesting to behove us to conduct this study on the vegetation impact on morphodynamic variability of the world's longest tropical river on an island, the Kapuas in West Kalimantan, Indonesia.

Living green plants absorb solar radiations as a source of energy in the photosynthetic process. The green pigment in the plant leaves strongly absorbs visible light (0.40 µm - 0.70 µm) for photosynthesis whereas the cell structure in the leaves strongly reflects near infrared light (from 0.70 µm - 1.1 µm). The more the leaves a plant has, the more these wavelengths of light are affected respectively. For this reason living green plants appear relatively dark in the visible region and relatively bright in the near infrared region. Among the spectral indices, NDVI is widely used to detect vegetation [18] and its effectiveness has been verified for terrestrial and wetland systems [19]. In some cases, a middle infrared band is also useful for the identification of vegetation. A few studies have found a better correlation between the reflectance in the middle infrared bands and the vegetation types. Due to the high water content in the forest leaves with a deep canopy structure, the middle infrared band shows a lower reflectance. For instance, Foody et al. [20] observed a high sensitivity of the middle infrared band in the estimation of the biomass of the Borneo tropical rain forest that led to conclusion that both Landsat band 5 and 4 are sensitive to biomass estimation. Lu et al. [21] found that middle infrared band is sensitive to the maturity of forest. Based on the above discussion, NDVI was chosen to identify the vegetation impact on the morphodynamic activity of the river Kapuas as the Kapuas passes through a tropical dense forest having a direct bearing on the morphological change of the river.

2. MATERIALS AND METHODS

Delineation of river banks of different time series is a prerequisite for a clear understanding of morphological dynamics of a river. This research used delineated river banks from a previous research by Huisman [14] 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 (Annex) where the migration rates found significant were selected to investigate the vegetation impact and the steps followed afterwards are shown in the Fig. 1.

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 an unsupervised classification and calculation of NDVI, ENVI4.8 was used as an operating tool. K-means classification with 16 classes and 16 iterations that were used to classify the land cover around the banks of the entire length of Kapuas (Fig. 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 or may not be the same.

For an 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 spectral profile of the area, it can be deduced which land cover types are belonging to which classified category. Based on the classification category, spectral profile and videos, vegetation types corresponding to an unsupervised classification category was selected. Next NDVI values of the selected categories were used as a unique tool to identify the vegetation and land cover types within the study area.

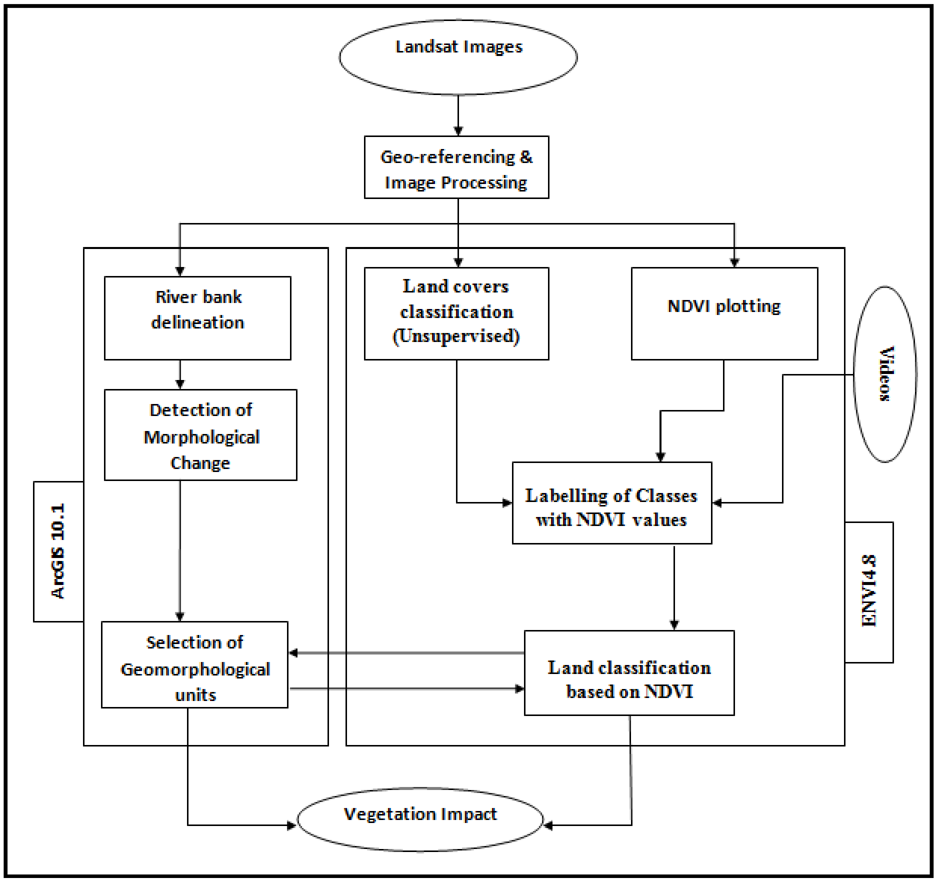

Fig. 1. Methodological flowchart for the investigation of vegetation impact

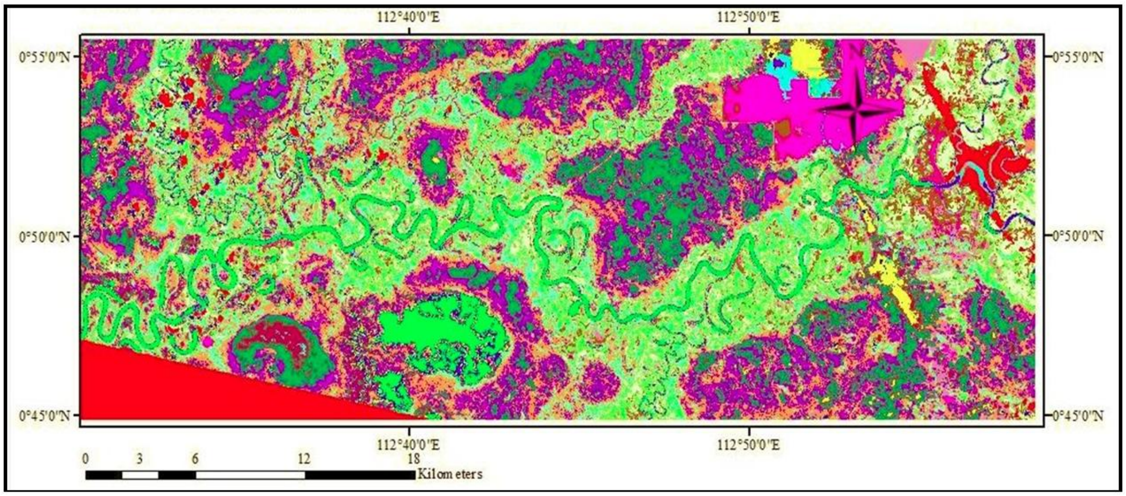

Fig. 2. Land cover classification of the upper upstream area of Kapuas

2.2 NDVI Calculation

To calculate the NDVI values of the entire Kapuas area for a time series, Landsat images were downloaded from USGS archive **(earthexplorer.usgs.gov/)**. Then the images were geo-referenced to the UTM, Zone 49 N coordinate system. Descriptions of the Landsat images of those used to calculate the NDVI in this study are given in the Table 1. Smaller pixel values usually give a better result for land cover investigation. In order 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 (Fig. 3) One pixel area (30 m x 30m) 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 round, the spectral profiles of middle infrared bands were used to separate the land covers as well as vegetation types.

Table 1. Detail of landsat images

Year	Landsat	Path/Row	World reference
1991	LT5	119/59, 120/59 & 121/60	WRS-2
1994	LT5	119/59 & 121/60	WRS-2
1995	LT5	119/59, 120/59 & 120/60	WRS-2
2001	LE7	119/59, 119/60, 120/60,121/59 & 121/60	WRS-2
2005	LT5	119/59, 120/59 & 120/60	WRS-2
2013	LC8	119/59, 120/59 & 121/60	WRS-2

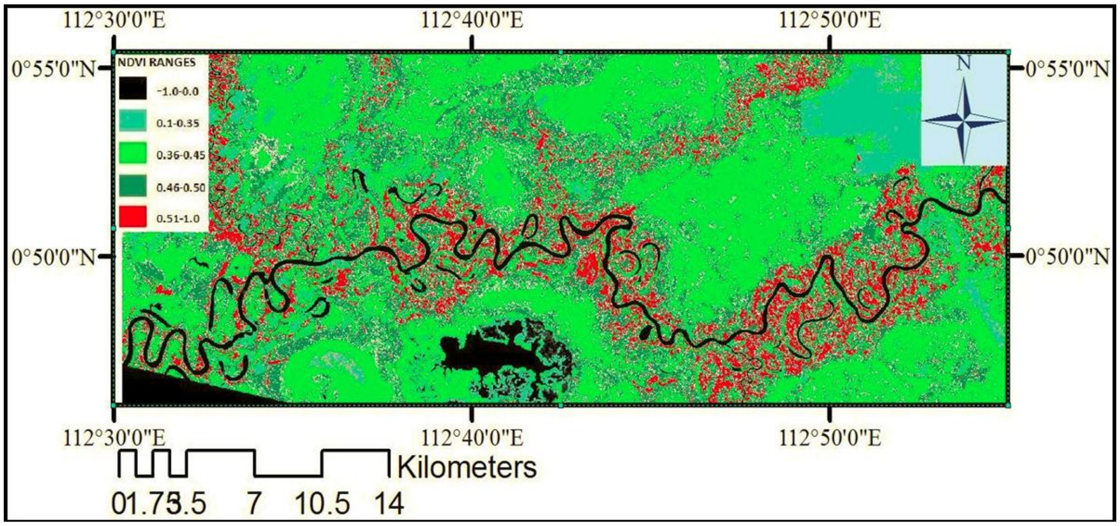

Fig. 3. NDVI map of the upper upstream of Kapuas River, 2013

3. RESULTS AND DISCUSSION

Throughout the entire length (upstream), both banks of the Kapuas were found more or less vegetated with different vegetation types. NDVI values corresponding to vegetation types (Fig. 4) clearly show that with increasing vegetation density and biomass, the NDVI values are found to increase. Beyond a certain range, NDVI becomes saturated for a higher biomass. Box et al. [22] suggested a saturation NDVI value of 0.40 while 0.54 was suggested by Santin-Janin et al. [23] for saturation in case of a higher biomass. In this study NDVI values larger than 0.45 are found for the vegetated area with a comparatively higher biomass whereas more than 0.50 shows saturation of the NDVI. Within the study area (upstream) along the entire banks it is found that river banks with NDVI values of 0.45 or less are mostly 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 [23,24] and aboveground biomass is positively correlated with the plant biomass below ground [25].

The size, depth and distribution of biomass below the ground, roots of trees, increases with an increase in size and lifespan of trees above ground [26], which in turn increase the soil shear strength [7] to protect from erosion. The pictures of the vegetation types (Fig. 4) with NDVI values clearly indicate 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.

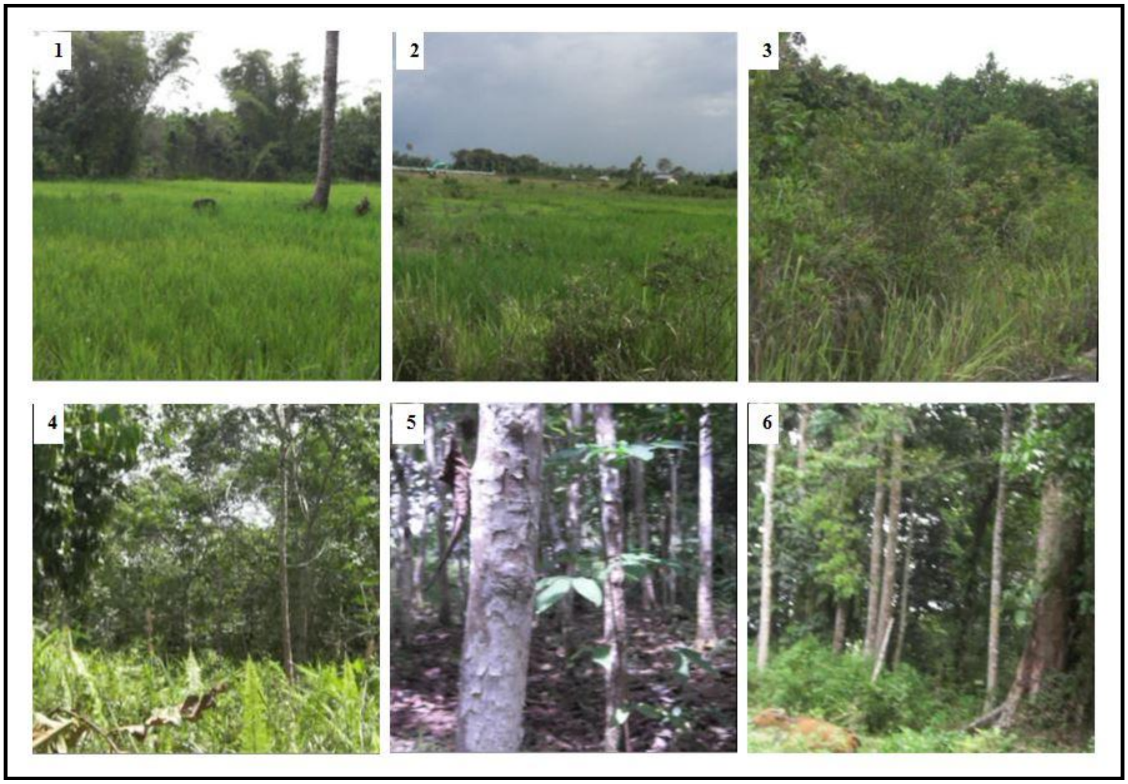

Fig. 4. Vegetation types and their corresponding increase in NDVI values. Land cover type 1 & 2 showing NDVI values 0.33-0.38; 3 & 4 showing NDVI values 0.40-0.45 and 5 & 6 showing values 0.48 and more

However, this study did not deal with other vegetation indices, 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 that 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 30m x 30m. Vegetation on the banks, which may not be visible in Landsat images due to not covering the whole pixel, can also give a good protection from the erosion process that is already observed from field work at stable banks [14]. In this case, contour lines of the same NDVI value that passes through the pixels to 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 as to protect from toe erosion or mass failure. It is also true that the root biomass distribution of all species of vegetation is not the same [27] but they can have a similar canopy structure which may give the same NDVI. For instance, primary tropical forest and secondary tropical forest may have a similar canopy structure that may lead to the same NDVI values, but their root biomass distribution below ground might be different as they have different biomass above ground [26]. 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 [20].

Moreover, some vegetation species may have root distribution that is much higher in the horizontal direction rather than in vertical direction under the ground or in the other way round. In that case the banks stability by vegetation would be different in terms of strength provided by root reinforcement. The depth of the river and variation of the water level also play a role in 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 a 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 do not penetrate to such depth like crops and shrubs [7].

Though Kapuas is the longest tropical river in Indonesia, it is not so deep and during the wet season its water level comes up causing flash floods overflowing the banks [28]. As the maximum bank erosion and migration occur during the peak discharge [29] and Kapuas banks overflow during the peaks [28], vegetation might play a role in the morphodynamic activity as it increases soil shear strength, gives bank stability and resists river bank widening [10], [30]. In this study, the impact of vegetation was focused mainly on the bends instead of straight rivers as maximum bank migration occurs around the bends [31] that makes the river morphologically more active. A high NDVI value indicates high vegetation biomass both above and below the ground [23-25]. Consequently, vegetation of a high NDVI will give comparatively high bank stability through dense root networks under the ground that impacts bank migration as well as morphodynamic activity.

4. CONCLUSION

The objective of this study was to have an insight into the vegetation impact on the morphodynamic activity of the river Kapuas. To address the objective, NDVI was used as a unique tool to identify the vegetation types, their corresponding biomass and finally its impact on the morphodynamic activity. Based on the results of this study, it is concluded that vegetation may impact positively on the morphodynamic activity of the river Kapuas consistent with on its health, density and biomass both above and below the ground. In terms of NDVI, it may also be concluded that river banks with a little vegetation, having NDVI values of 0.45 or less, are morphologically more active than the banks with dense vegetation, having NDVI values over 0.45.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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ANNEX

From the previous research it is found that bank migration rate of the river Kapuas was higher at the bends rather than the straight or other reaches. To observe the vegetation impact, nine morphological units were selected (Fig. 5) at nine bends where some portion of the river is migrated and some portions are stable.

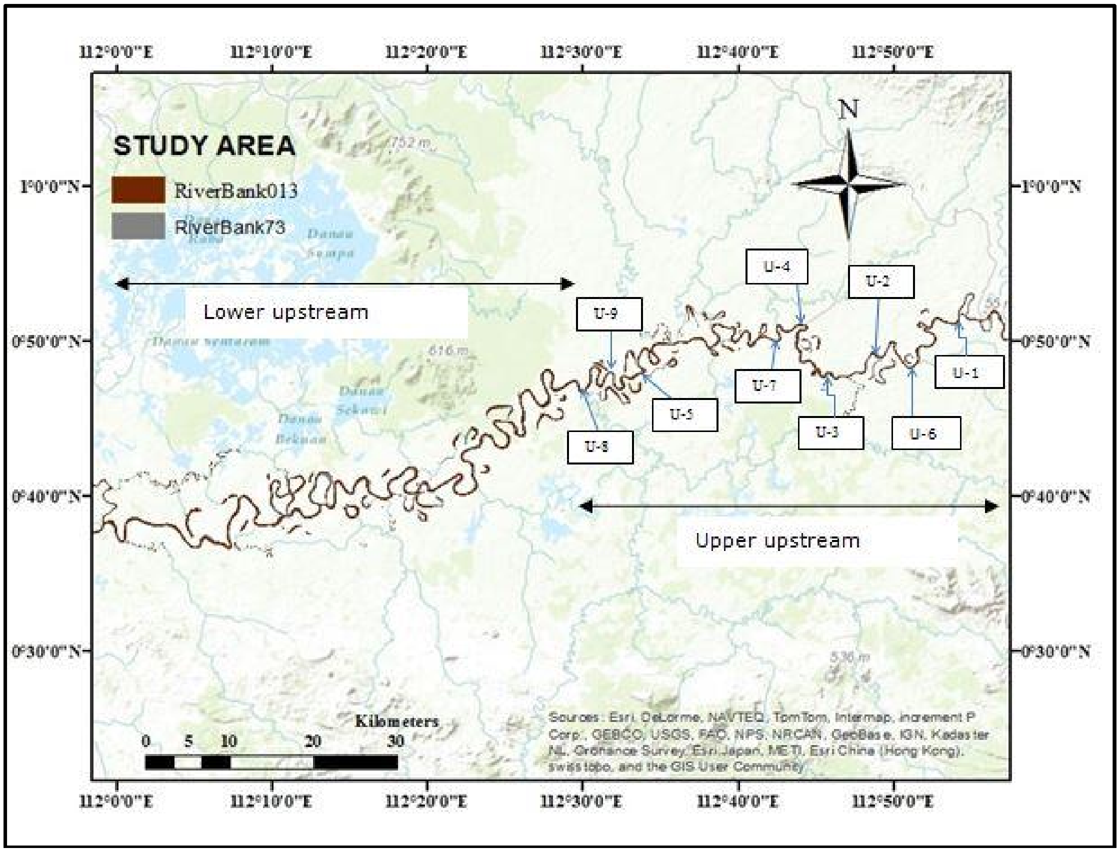


Fig. 5. Selected morphological study units in the upstream of the Kapuas

To show the clear migrated area, the morphological units were selected only in the upper upstream area as the migration rate was comparatively higher in the upper upstream area than the downstream area. The migrated areas are shown in the Fig. 6.

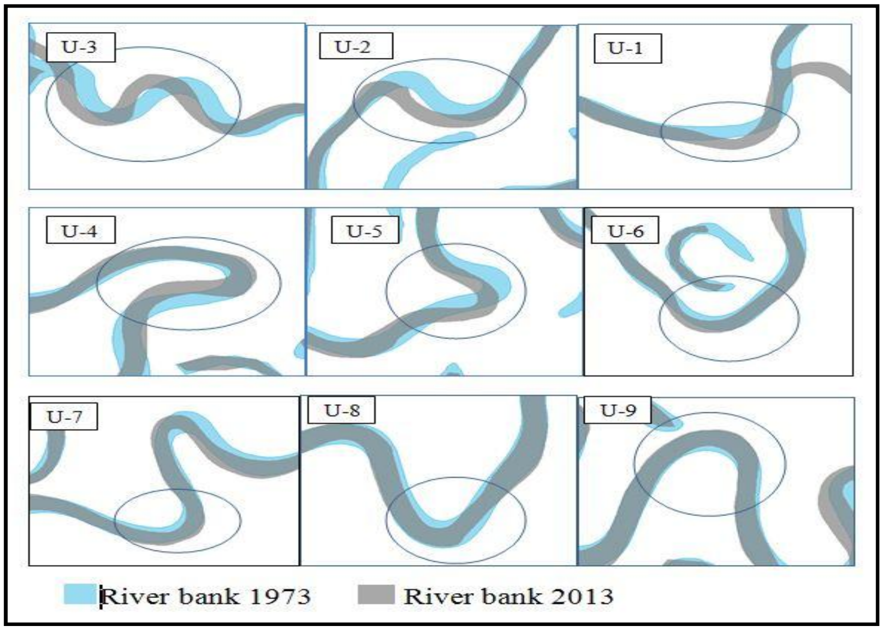


Fig. 6. Selected morphological units with focusing area (ellipse) in the upper upstream of kapuas river

NDVI values of 10 random points in different years on both migrated and stable banks are shown in the following tables.

Table 2. NDVI values at 10 random points along the banks in eroded area of study unit-1

Point no.	Year Location	1991	1994	2001	2005	2013	NDVI, average of different years in each point
I	112°53’59’’E 0°51’5.94’’N	0.382	0.354	0.364	0.354	-0.11	0.2688
II	112°53’53.10’’E 0°51’5.94’’	0.42	0.46	0.36	-0.04	-0.11	0.218
III	112°53’46.31’’E 0°51’4.97’’N	0.47	0.48	0.39	0.50	-0.06	0.356
IV	112°53’59’’E 0°51’3.01’’N	0.33	0.34	0.22	0.43	0.24	0.312
V	112°53’50.2’’E 0°51’4.96’’N	0.46	0.49	0.36	0.40	-0.10	0.322
VI	112°54’7.66’’E 0°51’9.84’’N	0.33	0.42	-0.242	-0.174	-0.09	0.0488
VII	112°53’59’’E 0°51’9.84’’N	0.49	0.45	0.30	0.36	-0.04	0.312
VIII	112°54’10.57’’E 0°51’10.81’’N	0.38	0.30	-0.11	-0.06	-0.04	0.094
IX	112°54’7.66’’E 0°51’7.89’’N	0.49	0.45	0.303	0.36	-0.04	0.3126
X	112°54’12.51’’E 0°51’14.72’’N	0.36	0.31	-0.37	-0.08	-0.02	0.04
NDVI, average of different points in each year.		0.4112	0.4054	0.1575	0.205	-0.037	0.22842

Table 3. NDVI values at 10 random points along the banks in eroded area of study unit-2

Point no.	Year Location	1991	1994	2001	2005	2013	NDVI, average of different years in each point
I	112°48’50’’E 0°49’5.96’’N	0.394	-0.09	-0.36	-0.22	-0.11	-0.0772
II	112°49’4.0’’E 0°48’55.0’’	0.43	1.07	-0.22	-0.20	-0.09	0.198
III	112°48’57.15’’E 0°48’57.17’’N	0.45	0.43	0.02	-0.08	-1.07	-0.05
IV	112°48’58.25’’E 0°48’59.07’’N	0.42	0.38	0.42	0.38	-0.11	0.298
V	112°48’43.0’’E 0°49’4.96’’N	0.44	0.408	0.409	0.205	-0.09	0.2744
VI	112°48’45.51’’E 0°49’8.90’’N	0.47	0.44	0.04	-0.16	-0.10	0.138
VII	112°48’47.45’’E 0°49’5.0’’N	0.48	0.34	0.26	-0.09	-0.09	0.18
VIII	112°48’48.42’’E 0°49’3.03’’N	0.50	0.35	0.36	0.33	0.07	0.322
IX	112°48’53.27’’E 0°48’57.17’’N	0.47	0.46	0.41	0.056	0.38	0.3552
X	112°49’4.60’’E 0°48’53.8’’N	0.47	0.39	0.20	-0.05	-0.06	0.19
NDVI, average of different points in each year.		0.453	0.42	0.154	0.017	-0.13	0.183

Table 4. NDVI values at 10 random points along the river bank within the eroded area of study unit-3

Point no.	Year Location	1991	1994	2001	2005	2013	NDVI, averages of different years in each point
I	112°46’6.06’’E 0°47’40.09’’N	0.29	-0.05	-0.03	-0.17	-0.101	-0.0122
II	112°46’2.48’’E 0°47’44.0’’	0.396	0.38	0.19	-0.189	-0.101	0.1352
III	112°45’44.36’’E 0°48’3.49’’N	0.33	0.50	0.12	-0.14	-0.10	0.142
IV	112°45’39.20’’E 0°47’58.66’’N	0.41	0.53	0.30	0.08	-0.02	0.26
V	112°45’36.29’’E 0°47’54.76’’N	0.39	0.52	0.41	0.34	-0.10	0.312
VI	112°45’34.35’’E 0°47’49.87’’N	0.42	0.29	0.38	0.44	-0.10	0.286
VII	112°45’25.61’’E 0°47’38.16’’N	0.39	0.32	0.10	0.10	0.08	0.198
VIII	112°45’20.76’’E 0°47’41.09’’N	0.40	0.33	-0.08	-0.22	-0.11	0.064
IX	112°45’11.06’’E 0°47’53.79’’N	0.38	0.51	0.34	0.31	-0.07	0.294
X	112°45’12.03’’E 0°47’50.86’’N	0.41	0.48	0.35	0.23	-0.09	0.276
NDVI, average of different points in each year.		0.382	0.381	0.208	0.078	-0.07	0.1955

Table 5. NDVI values within the eroded areas of study unit-4

Point no.	Year	1991	1994	2001	2005	2013	NDVI, averages of different years in each point
	Location						
I	112°44’3.65’’E 0°50’46.4’’N	0.25	0.48	-0.30	-0.22	-0.10	0.022
II	112°44’5.02’’E 00°50’47.13’’	0.51	0.59	0.142	0.20	-0.10	0.2684
III	112°44’8.78’’E 0°50’47.82’’N	0.58	0.56	-0.30	-0.20	-1.0	-0.072
IV	112°44’12.12’’E 0°50’48.16’’N	0.35	0.24	-0.34	-0.25	-0.10	-0.02
V	112°43’56.43’’E 0°50’45.71’’N	0.41	0.54	-0.13	-0.12	-0.04	0.132
VI	112°44’3.22’’E 0°50’48.64’’N	0.47	0.54	0.42	0.58	-0.09	0.384
VII	112°44’29.42’’E 0°50’54.49’’N	0.45	0.41	-0.19	0.30	-0.04	0.186
VIII	112°44’26.52’’E 0°51’0.35’’N	0.47	0.08	-0.02	0.47	0.101	0.2202
IX	112°43’38.97’’E 0°51’1.35’’N	0.43	0.40	0.05	0.24	-0.00	0.224
X	112°43’52.54’’E 0°50’20.32’’N	0.24	0.38	-0.16	0.18	-0.08	0.112
NDVI, average of different points in one year.		0.416	0.422	-0.082	0.118	-0.145	0.14566

Table 6. NDVI values within the stable areas of unit-4

Point no.	Year	1991	1994	2001	2005	2013	NDVI, averages of different years in each point
	Location						
I	112°44’31.36’’E 0°50’51.56’’N	0.52	0.47	0.40	0.68	0.46	0.506
II	112°44’30.40’’E 0°50’58.39’’N	0.53	0.52	0.30	0.104	0.54	0.3988
III	112°44’27.5’’E 0°50’41.8’’N	0.52	0.52	0.35	0.61	0.50	0.5
IV	112°44’17.8’’E 0°51’6.21’’N	0.55	0.60	0.26	0.54	0.48	0.486
V	112°44’6.14’’E 0°51’8.17’’N	0.50	0.45	0.34	0.48	0.51	0.456
VI	112°44’0.32’’E 0°51’9.15’’N	0.54	0.57	0.43	0.67	0.49	0.54
VII	112°44’0.32’’E 0°50’59.38’’N	0.56	0.49	0.32	0.66	0.51	0.508
VIII	112°44’4.20’’E 0°50’58.41’’N	0.49	0.52	0.34	0.63	0.49	0.494
IX	112°43’31.20’’E 0°50’40.84’’N	0.54	0.55	0.32	0.61	0.49	0.502
NDVI, average of different points in one year.		0.52	0.52	0.34	0.55	0.49	0.487

Table 7. NDVI values at 10 random points along the river bank within the stable area of study unit-7

Point no.	Year Location	1991	1994	2001	2005	2013	NDVI, averages of different years in each point
I	112°42’47.53”E 0°50’15.47”N	0.48	0.55	0.34	0.61	0.48	0.492
II	112°42’45.60”E 0°50’24.26”N	0.52	0.56	0.35	0.58	0.53	0.508
III	112°42’37.82”E 0°49’58.87”N	0.50	0.51	0.39	0.57	0.43	0.48
IV	112°42’12.60”E 0°50’1.81”N	0.52	0.44	0.31	0.41	0.37	0.41
V	112°42’28.14”E 0°50’35.01”N	0.54	0.56	0.35	0.64	0.52	0.522
VI	112°42’27.17”E 0°50’39.89”N	0.54	0.55	0.37	0.59	0.47	0.504
VII	112°42’26.20”E 0°50’42.82”N	0.58	0.56	0.39	0.63	0.53	0.538
VIII	112°42’25.23”E 0°50’55.52”N	0.56	0.63	0.45	0.63	0.48	0.55
IX	112°42’41.73”E 0°50’30.12”N	0.46	0.51	0.36	0.47	0.53	0.466
X	112°42’35.9”E 0°50’45.75”N	0.42	0.55	0.22	0.56	0.42	0.434
NDVI, average of different points in different years.		0.512	0.542	0.353	0.569	0.476	

Table 8. NDVI values at 10 random points along the river bank within the stable area of study unit-8

Point no.	Year Location	1991	1994	2001	2005	2013	NDVI, averages of different years in each point
I	112°32’3.21”E 0°47’54.11”N	0.49	0.59	-0.07	0.42	0.51	0.388
II	112°32’2.24”E 0°47’57.04”N	0.45	0.61	-0.09	0.65	0.53	0.43
III	112°31’58.36”E 0°48’2.90”N	0.43	0.56	0.34	0.65	0.54	0.504
IV	112°31’0.12”E 0°47’1.38”N	0.48	0.54	0.28	0.61	0.48	0.478
V	112°30’56.24”E 0°47’6.27”N	0.52	0.57	0.31	0.56	0.42	0.476
VI	112°30’44.61”E 0°47’29.72”N	0.55	0.57	0.35	0.63	0.48	0.516
VII	112°31’26.36”E 0°47’22.86”N	0.46	0.57	0.39	0.63	0.53	0.516
VIII	112°31’25.37”E 0°47’51.19”N	0.50	0.52	0.31	0.46	0.43	0.444
IX	112°31’46.72”E 0°48’5.83”N	0.36	0.55	0.31	0.56	0.48	0.452
X	112°32’3.21”E 0°47’55.08”N	0.48	0.59	-0.07	0.48	0.52	0.4
NDVI, average of different points in different years		0.472	0.567	0.206	0.565	0.492	0.46

Table 9. 6NDVI values at 10 random points along the river bank within the stable area of study unit-9

Point no.	Year Location	1991	1994	2001	2005	2013	NDVI, averages of different years in each point
I	112°31’54.47’’E 0°47’26.76’’N	0.50	0.53	0.27	0.46	0.46	0.444
II	112°32’4.17’’E 0°47’27.73’’N	0.49	0.52	0.27	0.60	0.60	0.496
III	112°32’5.14’’E 0°47’17.97’’N	0.44	0.58	0.31	0.60	0.60	0.506
IV	112°32’4.18’’E 0°47’50.20’’N	0.47	0.60	0.33	0.60	0.60	0.52
V	112°32’1.27’’E 0°47’59.0’’N	0.46	0.55	0.39	0.62	0.62	0.528
VI	112°31’46.72’’E 0°48’5.83’’N	0.36	0.55	0.31	0.56	0.56	0.468
VII	112°31’46.72’’E 0°47’57.04’’N	0.54	0.56	0.40	0.57	0.57	0.528
VIII	112°31’51.57’’E 0°47’55.09’’N	0.47	0.43	0.28	0.45	0.45	0.416
IX	112°31’22.46’’E 0°47’45.33’’N	0.51	0.54	0.34	0.50	0.50	0.478
X	112°31’36.04’’E 0°47’50.21’’N	0.51	0.58	0.33	0.56	0.56	0.508
NDVI, average of different points in different years.		0.475	0.544	0.323	0.552	0.552	0.4892

Example: Different banks of the river Kapuas

Mass failure of Banks without vegetation

Migrated banks without vegetation

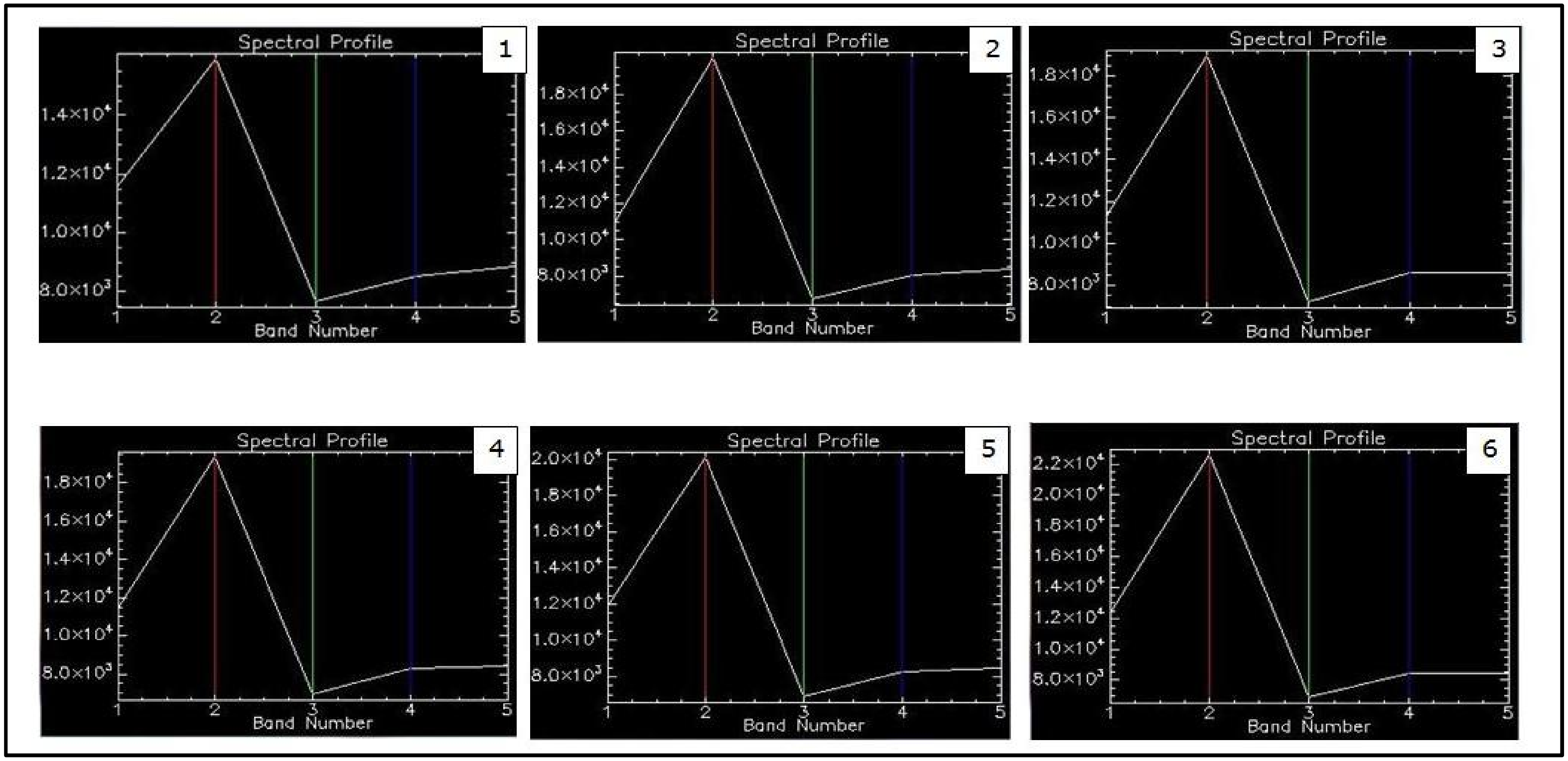
Stable bank with Vegetation

Stable bank with vegetation

Stable bank with vegetation

Stable bank with vegetation

Spectral profile:



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