Spatio-temporal analysis of river morphological changes and erosion detection using very high resolution satellite image

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Abstract. Spatio-temporal analysis of Kilim River using Very High-Resolution (VHR) satellite image between the years of 2005 and 2012 are vital to assess river morphological changes and erosion detection over the specific time duration. Therefore, this study utilizes remote sensing and Geographical Information System (GIS) capabilities to identify the channel migration and shifting as well as to calculate the rate of erosion and accretion. Classification of the river from Quickbird and WorldView-2 images is carry out using Maximum Likelihood Classification (MLC) technique whereas feature selection tool performs to extract river feature from the raw image. Subsequently, river feature been overlaid to identify the changes of riverbank pattern and to calculate the rate of riverbank erosion in terms of area. The result shows the total area of erosion is 27252.959 m^2 and the total area of accretion is 6079.999 m^2. A maximum erosion of 6993.102 m^2 detected at Section E while maximum accretion of 681.026 m^2 spotted at Section D. The rates of riverbank erosion are 3406.62 m^2 /year while the rates for accretion are 759.999 m^2/years between 2005 and 2012. Hence, the output of this study enables Langkawi Development Authority (LADA) and other stakeholders to recognize the specific location, which severely affected by erosion and accretion as well as to spot the area experienced huge river channel shifting.

1. Introduction

River, stream, and channel are types of natural watercourses on the surface of the earth and have become the crucial part of geological elements. The river channel course persistently shifted over space through time and has the tendency to attain equilibrium condition in order to adjust itself with the varying fluvial-geomorphic as well as a climatic condition [1]. This change occurs in various field including fluvial, glacial, arid, wind, coastal and karst morphology as the result of dynamic phenomena of the earth [2]. Channel morphology is the result of mutual interactions of four broad categories of variables such as fluid dynamics, (which includes velocity, discharge, roughness and shear stress) channel character or channel configuration (includes channel width, depth, and materials) [3].

Riverbank erosion has important implications for short and long-term channel adjustment, development of meanders, sediment dynamics of the river catchment, riparian land loss and downstream sedimentation problems [4]. Understanding the ways in which river channel have migrated through time is critical to tackling many geomorphic and river management problems, because of large magnitude as well as rates of change is necessary to measure and monitor channel migration [5]. Straight, irregular sinuous, meandering and braided are the type of river channel forms. Meandering river is shifting their course across the valley bottom by depositing sediment on the inside of bends while simultaneously eroding on the concave side of banks of the meander [6]. A better understanding of morphological changes of alluvial rivers, bank shifting, channel migration due to erosion and accretion process as well as technique to detect resultant pattern would be useful for management of the alluvial environments [7].

This study aimed to identify the spatio-temporal changes in river morphology and erosion detection using VHR satellite image of Kilim River from 2005 to 2012, about 7 years apart. Remote sensing technique including geometric correction, image fusion (panchromatic sharpening), subset (AOI) and MLC as well as GIS technique such as image overlay, area calculation, feature extraction and symmetrical difference tool are utilize to analyze the morphological changes of Kilim River channel over annual time lapse. The analysis enables the researchers to assess the change detection of river and erosion by performing digital image processing on temporal satellite image as well as illustrating the pattern and river channel shifting over time. The utilization of remote sensing is capable to providing a synoptic view of the large area at regular intervals with quick turn-around time integrated with GIS techniques, making it ideal for monitoring riverbank erosion as well as riverbank borderline shifting [8].

2. Materials and Methods

2.1. Study area
Kilim River (6°21.518´-6°26.093´N and 99°49.091´- 99°51.159´E) is located at the northeast region of Langkawi Island, west coast of Peninsular Malaysia (Figure 1) [9]. Kilim River is part of river channel originated from the coastal area and known as the main entrance to Kilim Geoforest Park. Kilim River is included as one of intertidal zone and experienced semi-diurnal tide [10]. This region experiences rapid changes demographically from a rural area, comprised of a traditional village, mangrove forest, limestone hills and various species of flora and fauna, into a famous tourist destination in Langkawi Island after having been declared as Geoforest Park on July 2007 [11] [12] [13].

2.2. Data selection (materials)
Quickbird image (2005) and WorldView-2 (2012) were used to quantify the changes in river channel morphology of Kilim River, and both images are acquired by purchasing through vendors. The selection of data mainly depends on its spatial, temporal, spectral characteristic, time availability and the most important is the price. Quickbird image of 2005 was chosen because the Kilim area had still not been declared as Geoforest Park status and Kilim River was not severely affected by erosion at that time [14]. WorldView-2 image of 2012 was chosen in order to analyze the change of river morphology, a few years after the declaration of Kilim area as Geoforest Park in July 2007. The time duration between both images is sufficient to portray river changes.

2.3. Data processing (methods)
2.3.1. Pre-processing. Both images of Quickbird and WorldView-2 covered about 5km x 5km of earth surface at the northeast area of Langkawi Island as the original scene and the study area are much smaller than the entire scene. Somehow, the required part of the image from original scene must be extracted using subset technique in ENVI software. Extraction the required study area is execute by using Area of

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Interest (AOI) technique consist of rectangular, circle or irregular shape of AOI tools [15]. Both images with different study years been extracted within the exact size of the rectangle and cover the same region precisely.

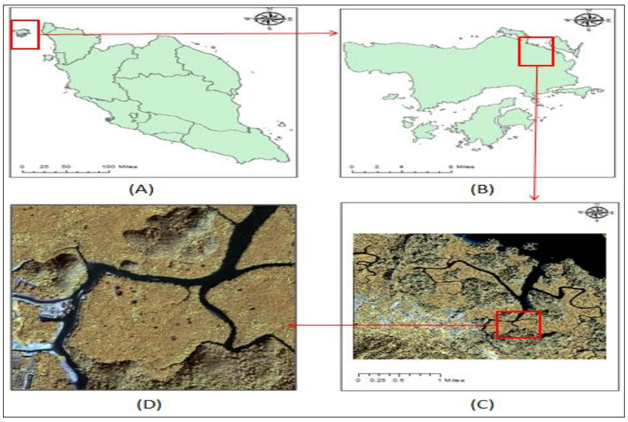

Figure 1. Location of Study Area (A: Peninsular Malaysia), (B: Langkawi Island), (C: Full Image of Satellite Image) and (D: Area of Interest (AOI)

2.3.2. Maximum likelihood classification (MLC). The extraction of certain features and analysis of subset images of the study area is through classification method. Image classification is the process of clustering the image into one of a number of predefined categories [16]. If the pixel satisfies the certain set of criteria, then the pixel is assigned to those classes according to the criteria. Image classification is divided into two main techniques, supervised and unsupervised, which have a different algorithm in categorizing the pixel according to assigned classes. Riverbank erosion is usually occurring at the mixture area between two or more pixel value and requires specific techniques to identify this feature. In this study, riverbank erosion occurs at the boundary line (or normally called river shoreline) between river and non-river, especially at general area. In this study, supervised classification is used to classify the pixel value that belongs to river shoreline class in order to identify riverbank erosion. MLC method performed well with cloud edge detection over water compared to other supervised methods such as parallelepiped and hybrid classification [17]. The advantage of using MLC as a parametric classifier is that it takes into account the variance-covariance within the class distribution data and for normally distributed data, the MLC performs better than the other parametric classifiers. MLC algorithm is described as below:

$$P(v \mid C_i) = (2\pi)^{-\frac{N}{2}} \mid Y_i \mid ^{-\frac{1}{2}} exp\{-\frac{1}{2}(v - Zi)^T\} Y_i^{-1}(v\text{-}Zi) \quad (1)$$

where P (v $\mid C_i$) as a multivariate normal distribution that is also known as a Gaussian distribution, N represent the number of classes for determining the class of a particular pixel with measurement vector v, the conditional probabilities, C_1 as Classes can be represented in Baye's classication and , Z_i and Y_i is mean vector and covariance matrix of the data in class C_i.

2.3.3. Vector image overlay. Image overlay is the process of superimposing multiple datasets to identify the relationships between them. It is enlisted as GIS operation which tends to create a composite map by combining the geometry and attributes of the input datasets. In this study, vector datasets from the classified image which are the classified image of Quickbird (2005) are being merged with the classified image of WorldView-2 (2012). Erase function in overlay tools was utilized to create a feature class by overlaying the input feature with the Symmetrical Difference and Erase tools. Symmetrical Difference is the process which enables the features in the input and update features that do not overlap will be written to the output feature class. Meanwhile, Erase tool is the process of creating the feature by overlaying the input features with the polygons of the features and only those portions of the input feature falling outside the erase features outside boundaries are copied to the output feature class.

3. Result and Discussion

3.1. River morphological changes

Variation of the channel at Kilim River is being tabulated and visualized using statistical approaches in Figure 3, 4, 5 and 6. In Figure 2, river channel migration is being analyzed by measuring the distance from the control point and river borderline on both sides of the river (right and left bank). River morphological changes are recognized by measuring river shift, whether the river channels towards outer banks or inner side of riverbanks. The river migration towards the outer side of the riverbank is considered as having erosion and will be marked as the negative value in the table, while the river migration towards the inner side of riverbanks is considered as having accretion and will be marked as the positive value in the table.

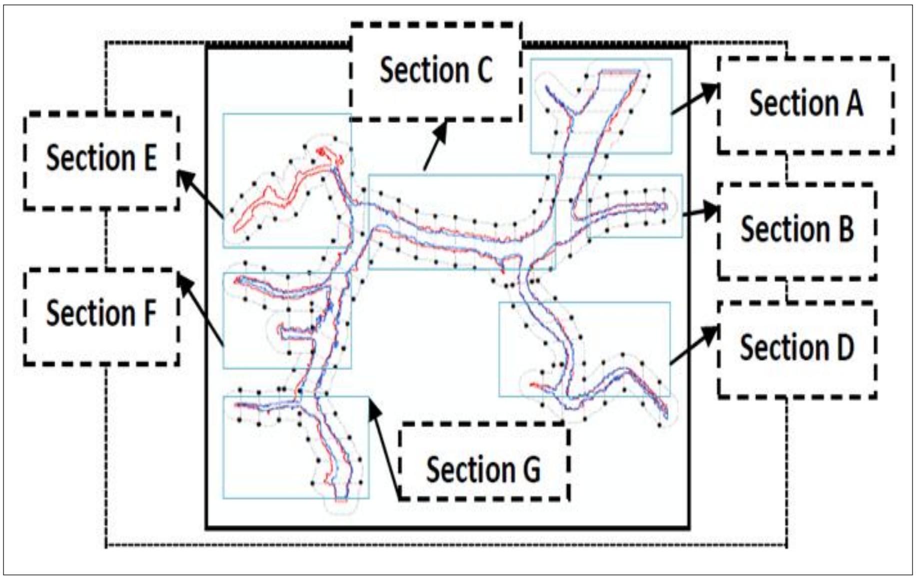

Figure 2. River channel migration

The tabulated data of river channel changes is then generated into line chart in order to visualize trend over time. In general, river shifting and channel migration really occur at Kilim River and some parts at Kilim are having a serious problem, especially erosion problem. Erosion tends to broaden the river and causes any building structures or plantation to be eroded and end up falling into the river. At section C, E, F, and G, the tabulated channel shifting shows that most of the area indicates the negative value which simply classifies the area under serious erosion problem. However, section D plotting the positive average value at both sides of the riverbank and shows that that region is still away from erosion threat. The biggest value of accretion is +12.377 m at section G (Figure 6) and the biggest value of erosion is -20.383 m, recorded at section E (Figure 5).

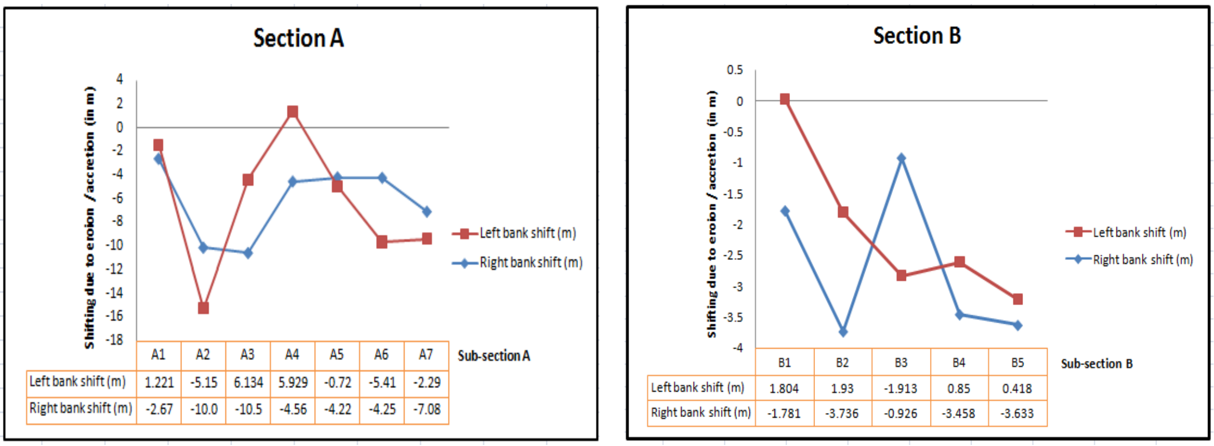

Figure 3. River channel changes of Section A and B between 2005 and 2012

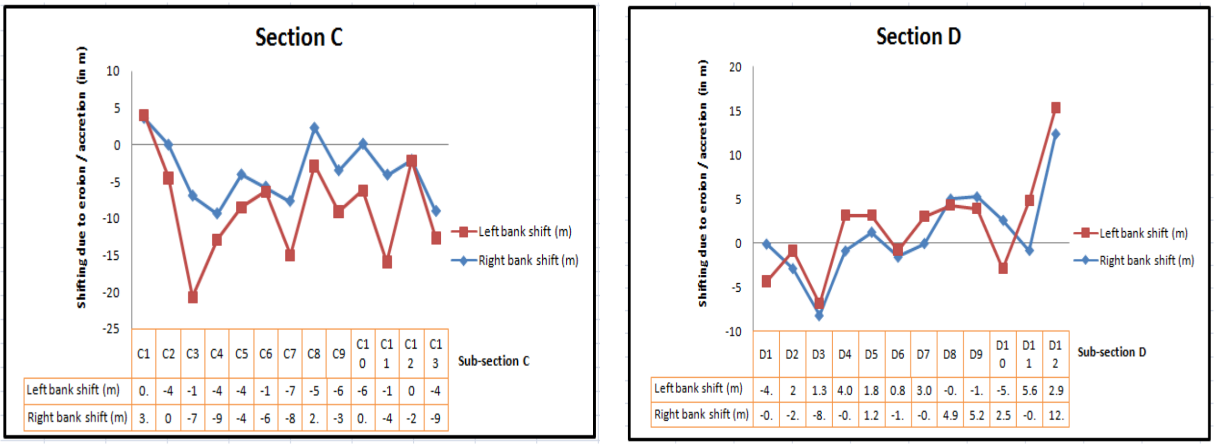

Figure 4. River channel changes of Section C and D between 2005 and 2012

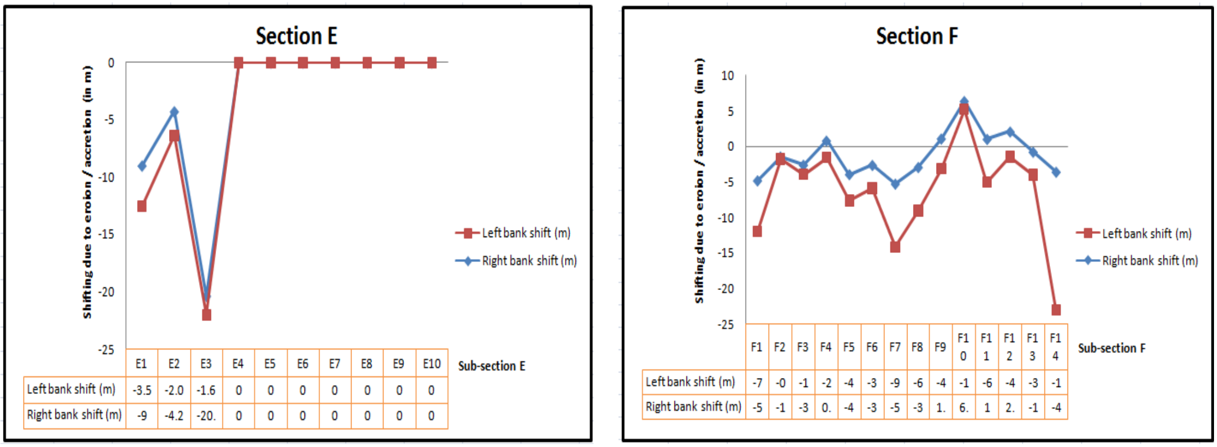

Figure 5. River channel changes of Section E and F between 2005 and 2012

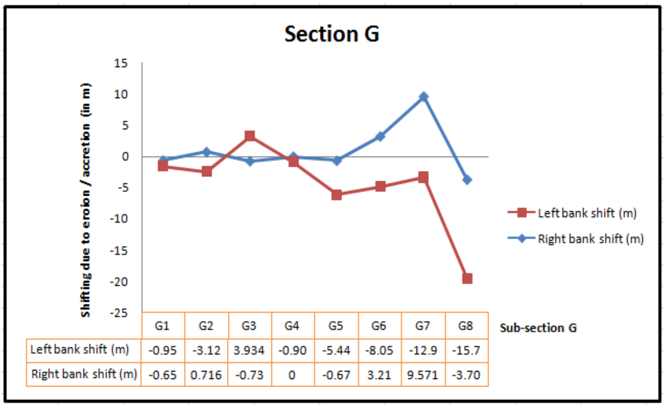

Figure 6. River channel changes of Section G between 2005 and 2012

3.2. Riverbank erosion and accretion detection

Riverbank erosion and accretion trend between 2005 and 2012 is represented in Figure 7. In general, almost the entire area of Kilim River is changed due to riverbank erosion and accretion due to the time frame. According to Figure 7, riverbank erosion looks noticeable along the main river due to the intensification of boat rental service for ecotourism purposes. The number of boats drifting through this river is increasing every day and the traffic in this area is very hectic especially during weekend and public holidays. The continuous movement of the boats will trigger boat wakes which could harm riverbank if hit continuously. This factor could contribute to erosion and it is logically shown Figure 7 when the main river, particularly section C, is experiencing erosion on both sides.

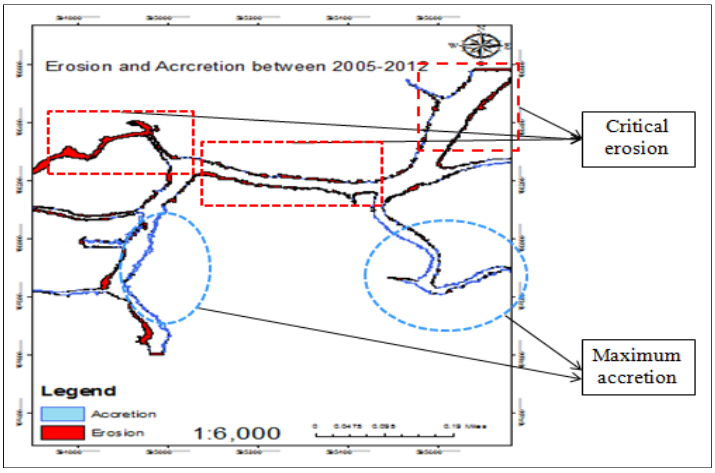

Figure 7. Riverbank erosion and accretion between year of 2005 and 2012 at Kilim River

The erosion is clearly shown in section E which recorded the most eroded area, -20.383 m and the reason for this value is because of the reconstruction of the channel for fisherman jetty. The reconstruction required river to be expanded to enable smooth of boat traffic toward the fisherman jetty and it aims to segregate between boat rental for ecotourism and fisherman purposes. The other location which seems significant for erosion is at section G, and the reason is frequent boat wakes in that region. There is a hotspot at section G, namely Gua Kelawar, and the crowded boats heading there will cause erosion. The same situation applies to section C.

Based on the map in Figure 7, accretion apparently exists at the sub-river channel, as it appears in section A and D, as well as some part of section A, F, and G. The reason is that sub-river channel is not exposed with overwhelming traffic like main river channel. Sub-river channel is only used by local fisherman and nature lovers. The location of the sub-river channel, such as section B and D, which are remote and deep in mangrove forest, make it more isolated from human intervention, thus enabling riverbank accretion to occur frequently. Locations of section B and D are also protected from tropical wind sources from the coastal area which could trigger waves that erode the riverbank. There are also accretions at main river channel, like in section F and G, which are located in the speed-limit zone and the boat cannot accelerate more than specific knot to avoid massive boat wakes.

Table 1. Erosion and accretion rate from 2005-2012

	Total area (m²)		Right bank (m²)		Left bank (m²)	
Time Span	Erosion	Accretion	Erosion	Accretion	Erosion	Accretion
2005-2012	27252.959	6079.999	15927.617	3505.911	11325.342	2574.088

The area affected by erosion and accretion is calculated in Table 1, showing the total number, as well as erosion and accretion per side. The table showed the total area of erosion from 2005 and 2012 is 27252 m² while the total area of accretion is 6079 m² within 7-years duration. Riverbank loss is spotted more at the right side of riverbanks compared to the left side, while the accretion is more dominant at the right side than the left side of Kilim River. The maximum erosion is detected in section E, about 6993.102 m² while the minimum erosion was detected at section D, about 0.034 m². For accretion, the maximum value is spotted at section D, 681.026 m² and the minimum value is 0.001 m², at section B of Kilim River.

Based on Table 1, total net loss of kilim Riverbank could be determined by subtracting the total value of erosion and the total value of accretion. An area of 21172.96 m² of Kilim riverbank (both side) was lost due to erosion and other potential factors such as sea level rise, wind from monsoon season and human intrusion. The right side of Kilim riverbank had lost 12421.706 m² while the left side recorded 8751.254 m² net losses within 7 years. The rate of riverbank erosion at Kilim River was calculated as 3406.62 m²/ year from 2005 to 2012, while the rate of accretion was identified as 759.999 m²/ year, respectively.

4. Conclusion

Duration of 7 years between two VHR images clearly illustrates massive changes of river morphology and displays erosion along with accretion. GIS and remote sensing technique are really resourceful and efficient in assessing the erosion rates and river channel migration, without the need for field measurement at the sites. Few capabilities from GIS such as feature selection, calculate geometry, measure, erase and symmetrical difference as well as geometric correction, subset (AOI) and MLC from remote sensing are effective to determine the channel migration and erosion rates at Kilim River. The results enable local authority such as LADA and Maritime Department of Langkawi to take action and impose appropriate solutions so; as to minimize the effect of erosion from keep harm the ecosystem of Kilim River, specifically.

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