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Application of PALSAR-2 remote sensing data for structural geology and topographic mapping in Kelantan river basin, Malaysia

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Abstract. Natural hazards of geological origin are one of major problem during heavy monsoons rainfall in Kelantan state, peninsular Malaysia. Several landslides occur in this region are obviously connected to geological and topographical features, every year. Satellite synthetic aperture radar (SAR) data are particularly applicable for detection of geological structural and topographical features in tropical conditions. In this study, Phased Array type L-band Synthetic Aperture Radar (PALSAR-2), remote sensing data were used to identify high potential risk and susceptible zones for landslide in the Kelantan river basin. Adaptive Local Sigma filter was selected and applied to accomplish speckle reduction and preserving both edges and features in PALSAR-2 fine mode observation images. Different polarization images were integrated to enhance geological structures. Additionally, directional filters were applied to the PALSAR-2 Local Sigma resultant image for edge enhancement and detailed identification of linear features. Several faults, drainage patterns and lithological contact layers were identified at regional scale. In order to assess the results, fieldwork and GPS survey were conducted in the landslide affected zones in the Kelantan river basin. Results demonstrate the most of the landslides were associated with N-S, NNW-SSE and NE-SW trending faults, angulate drainage pattern and metamorphic and Quaternary units. Consequently, geologic structural map were produced for Kelantan river basin using recent PALSAR-2 data, which could be broadly applicable for landslide hazard assessment and delineation of high potential risk and susceptible areas. Landslide mitigation programmes could be conducted in the landslide recurrence regions for reducing catastrophes leading to economic losses and death.

1. Introduction

The state of Kelantan is located in north-eastern corner of Peninsular Malaysia (Figure 1). Kelantan river is the major river in the region. It appears at the convergence of the Galas river and Lebir river near Kuala Kari and meanders over the coastal plain until it finally degrades into the South China Sea. Kelantan river basin covers 923 km^2, which is about 85% of the

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Kelantan state's surface area. It is composed of flat slope to moderately sloping areas in northern part and steep scraps and high slopes in the southern part of the river basin [1]. A wide variety of rocks consisting of igneous, sedimentary and metamorphic rocks could be seen in the state of Kelantan, which are distributed in a north-south trend. Typically, four types of rocks are classified in the region, including granitic rocks, sedimentary/metasedimentary rocks, extrusive rocks (volcanic rocks) and unconsolidated sediments (Figure 2). Localised geological features comprise folding, faulting and jointing in the sedimentary rocks and faulting and jointing in the granitic rocks.

Figure 1. Location of the Kelantan state in Peninsular Malaysia.

Yearly, several landslides occur during heavy monsoon rainfall in Kelantan river basin, peninsular Malaysia, which are obviously connected to geological structures and topographical features of the region. In recent years especially, there have been many severe flooding events (in the year 2005, 2006, 2007, 2008, 2009 and 2014) which have led to significant damage to livestock, agricultural produce, homes and businesses in the Kelantan river basin [2]. The problem stems from the inappropriate use of lands that are vulnerable to erosion, quick water runoff and slope failure. Recent challenge is to identify high potential risk and susceptible zones for natural hazards of geological origin in the Kelantan river basin using advanced remote sensing technology. In this study, the recently launched ALOS-2-Phased Array type L-band Synthetic Aperture Radar-2 (PALSAR-2), remote sensing data were used to identify high potential risk and susceptible zones for geological origin hazards in the Kelantan river basin at regional and district scales.

2. Materials

In this investigation, a ScanSAR mode dual polarization (level 3.1) and two Fine mode dual polarization (level 3.1) PALSAR-2 scenes were obtained from ALOS-2 data distribution consortium online system Remote Sensing Technology Center of Japan (RESTEC) (http://www.restec.or.jp/english/index.html) and PASCO Corporation (http://en.alos-pasco.com; https://satpf.jp/) for comprehensive analysis of major geological structures and detailed characterizations of lineaments in the state of Kelantan. In particular, L-band microwave from PALSAR-2 has ability to penetrate vegetation due to relatively long wavelengths (about 24 cm), making the data particularly useful for geological structural mapping in tropical environments [3,4]. The wavelength of the L-band is relatively long among microwaves (C-band: about 6 cm and X- band: about 3 cm), allowing it to travel all the way down to the ground through vegetation. Not only can information be, obtained about vegetation but information of the ground surface can be obtained as well [5,6]. The data were processed using the ENVI (Environment for Visualizing Images) version 5.1 software package.

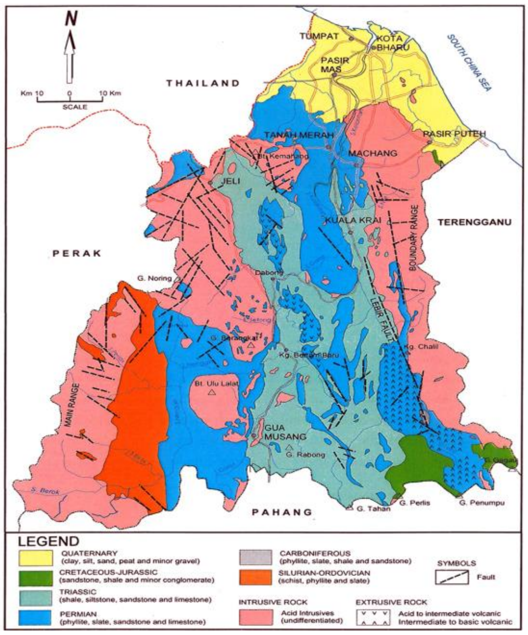

Figure 2. Geologic map of the Kelantan state [2].

3. Methods

In this study, the adaptive Local Sigma filter was selected and applied to accomplish speckle reduction and preserving both edges and features. The Local Sigma filter uses the local standard deviation computed for the filter box to determine valid pixels within the filter window. It replaces the pixel being filtered with the mean calculated using only the valid pixels within the filter box [7]. Directional filtering technique was applied to the Local Sigma resultant image for detailed lineament extraction and edge enhancement. Directional filter is used for producing artificial effects suggesting tectonically controlled linear features. It is a straightforward method for extracting edges in the spatial domain that approximates the first derivative between two adjacent pixels. The algorithm produces the first difference of the image input in the horizontal, vertical, and diagonal directions [8]. As a result, many additional edges of diverse orientations are enhanced. Edge enhancement is performed by convolving the original data with a weighted mask or kernel. Directional filters were used to enhance specific linear trends in the Local Sigma resultant images. Four principal Directional filters: N-S, E-W, NE-SW, and NW-SE with a 7*7 kernel size were applied. Directional filter angles were adjusted as N-S: 0˚, E-W: 90˚, NE-SW: 45˚, and NW-SE: 135˚. North (up) is zero degrees and the other angles are measured in the counterclockwise direction. A Global Positioning System (GPS) survey was carried out using a Garmin® MONTANA® 650 to provide accurate locations for landslide affected zones. Additionally, image processing results were compared with the geological and general topography maps of Kelantan state (1:100,000 scale).

4. Results and discussion

Figure 3 shows ScanSAR HV polarization image that is superimposed by general topography map of the Kelantan state. It is evident that the morphology of any area is largely controlled by rock type and structure. High elevation areas (500-100 m and <1000 m) in the Kelantan state are mountainous areas associated with Main Range granites (in the west) and Boundary Range granite (in the east), which are detected as grey to cream colour in ScanSAR image. Hilly, plain and coastal areas with altitude between 500 to 50 m are associated with sedimentary rocks, which are manifested pink to yellow colour in ScanSAR image.

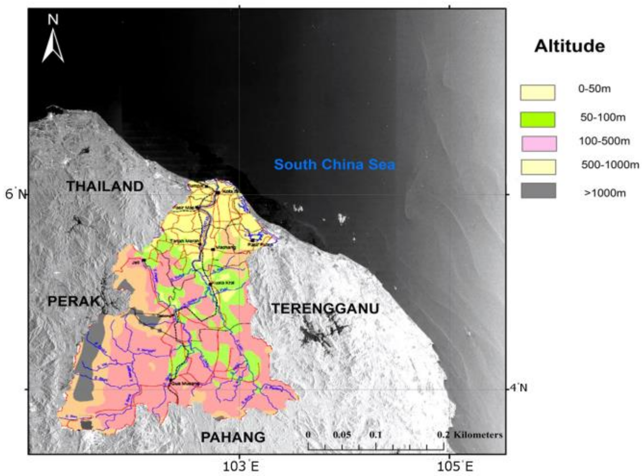

Figure 3. ScanSAR HV polarization image of the Kelantan state superimposed by general topography map.

Figure 4 shows the results of RGB colour-composite for N-S, NE-SW, and NW-SE (R: 0°, G: 45°, B: 135°) directional filters. Major change in deformation style is obvious from the west to the east in Figure 6. Structural analysis reveals four distinct parts from the west to the east, including (ii) western part of the scene by ductile fabrics; (ii) western of the Bentong-Raub Suture Zone (BRSZ) affected mainly by brittle deformation; (iii) ductile-brittle deformation between the BRSZ and Lebir Fault Zone; and (iv) brittle-ductile fabrics between Lebir Fault Zone and eastern coastal line. Lineament occurrence in Figure 4 is mainly linked to the N-S trending of the BRSZ and Lebir Fault Zone. Generally, major faults are strike-slip with both dextral and sinistral movements, which trend N-S and NW-SE. NW-SE trending strike-slip faults moved sinistrally in the Lebir Fault Zone. The sinistral movement along the Lebir Fault Zone is responsible to the formation of folding and reverse faulting adjacent to the fault and surrounding area. The collision zone and compressional structures appear clearly in the west of the BRSZ in Main Range granites (Figure 4). Deformation in this region shows the shortening zone oriented parallel to the BRSZ. Several faults, joints and fractures represent brittle deformation events in the region that mostly strike NW-SE. Generally, most of the short lineaments are clustered in the collision zone. Ductile deformation in the western margin of the image (Figure 4) includes upright asymmetrical mega folds with axial surfaces oriented W-E. The deformed area zone between the BRSZ and Lebir Fault Zone represents faults system and folded area. Brittle-ductile fabrics in the eastern part of image between

Lebir Fault Zone and eastern coastal line illustrate curved shear zone that occupied by several N-S and NW-SE striking faults, fractures and joints.

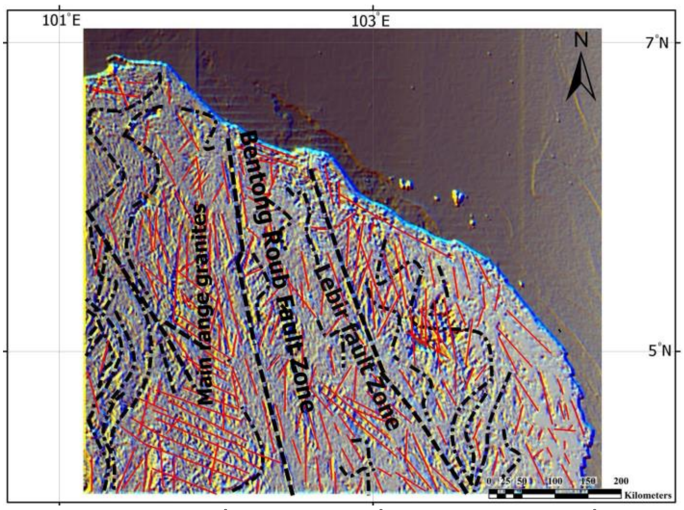

Figure 4. RGB colour-composite of N-S (0°), NE-SW (45°), and NW-SE (135°) directional filters of northern part of Peninsular Malaysia.

Figure 5 shows geologic structural map for the Kelantan state. It is produced based on the integration of directional filter images for fine PALSAR-2 scenes of northern and southern parts of Kelantan. The most important feature in the map is the presence of river systems, drainage lines patterns and fault zones. The N-S, NE-SW and NNE-SSW lineament trends are commonly dominant in the image map (Figure 5). Additionally, few short NW-SE trending lineaments are detected in the western and eastern parts of the study area. The dominant lineaments tend to run in the N-S direction. Pattern of the lineament map suggest that some faults belong to the Lebir Fault Zone are detected in south-eastern part of the image. They are N-S and NE-SW striking system distributed in the south eastern part of Kelantan. On the contrary, pattern of the lineament map in north-western part of the image map displays the occurrence of BRSZ fault zone, which contains lineaments in N-S and NNE-SSW direction. The rivers in the study area are structurally controlled. The drainage of the Kelantan river basin shows dendritic, sub-dendritic and rectangular pattern in most part of the region. Surface drainage patterns are controlled by lithology and geological structures. Dendritic and sub-dendritic patterns with a large number of tributaries are typical of drainage in areas of impermeable crystalline rock such as gneiss. It is the most common drainage pattern and is characteristic of essentially flat-lying and/or relatively homogeneous rocks and impervious soils and lack of structural control. Rectangular pattern is usually caused by jointing or faulting of the underlying bedrocks. It is usually associated with massive, intrusive igneous and metamorphic rocks. Therefore, the area with dendritic and sub-dendritic patterns is subjected to hydro-geological hazards such as flooding because of low infiltration runoff. Rectangular drainage pattern is susceptible zone that could be affected by landslide easily due to slope of the land, litho-structural conditions and speed of runoff. Results of fieldwork verified that the most of the landslides were associated with N-S, NNW-SSE and NE-SW trending faults, angulate drainage pattern and metamorphic and Quaternary units.

5. Conclusions

The results presented in this study demonstrate the importance and advantages of the use recently launched PALSAR-2 data for geological structural mapping in the Kelantan state, north of Peninsular Malaysia. The state of Kelantan is located between two significant fault zones, including the Bentong-Raub Suture Zone and Lebir Fault Zone. Most of the landslide affected areas were associated with N-S, NNW-SSE and NE-SW trending faults, angulate drainage pattern and metamorphic and Quaternary units. Results of this investigation could be considered for governmental or private construction projects in the landslide recurrence regions for reducing catastrophes leading to economic losses and death.

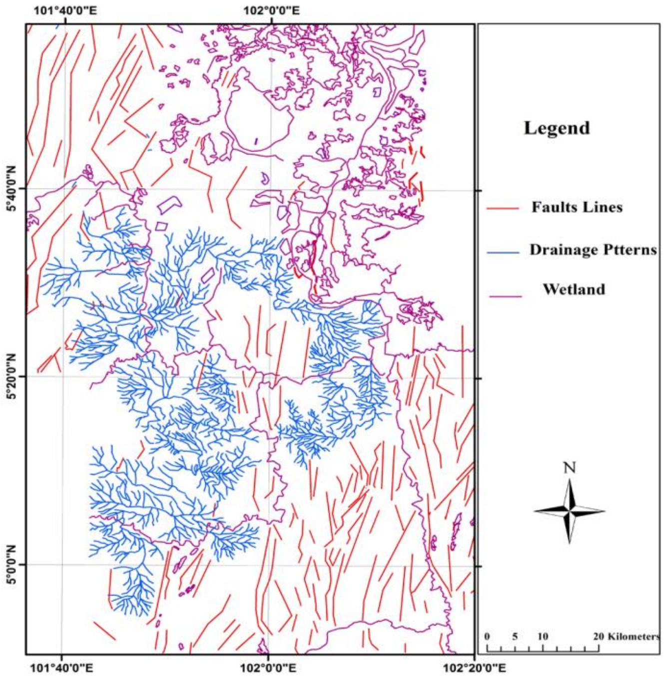

Figure 5. Geologic structural map for the Kelantan state derived from directional filtering images.

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