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Best Band Ratio Combinations for the Lithological Discrimination of the Dayang Bunting and Tuba Islands, Langkawi, Malaysia

(Gabungan Nisbah Jalur Terbaik untuk Diskriminasi Litologi di Pulau Dayang Bunting dan Pulau Tuba, Langkawi, Malaysia)

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ABSTRACT

Band ratio combination has been proven to be one of the most useful image processing methods for lithological discrimination, as discussed by many researchers in the past. In this study, bands from Landsat 5 TM were used to generate different ratio combinations to discriminate the different lithologies of two islands located at the southern end of the Langkawi archipelago, specifically the Dayang Bunting and Tuba Islands. Both islands comprise similar lithological units – namely, limestone/marble (Permian & Silurian-Ordovician), granite and alluvium. There are two rock formations that are limestone/marble dominated. The first is known as the Chuping Formation, which consists of limestone/marble and the other is the Setul Formation, which consists of not only limestone/marble but also of two detrital intervals. Different ratio combinations obtained from past researchers and that was produced from this study were tested on the image of the Dayang Bunting and Tuba Islands to identify the best ratio combinations that were able to discriminate the different lithologies for both islands. A total of 28 combinations were performed to examine which combinations are the most effective. From the 28 combinations, three were identified as the most suitable; 4/3 5/2 3/1, 5/3 4/3 4/1 and 4/2 5/3 4/3 in the RGB sequence. These combinations enhanced the spectral differences of each lithology unit so that it can be distinguished easily. Apart from the difference in the spectral response, the texture of the lithologies was also enhanced to assist in discriminating the different units.

Keywords: Band ratio combination; Landsat TM; Langkawi; lithological discrimination; spectral response

ABSTRAK

Gabungan nisbah jalur telah terbukti menjadi salah satu kaedah penting dalam pemprosesan imej untuk mengenal pasti diskriminasi litologi, seperti yang telah dibincangkan oleh ramai penyelidik terdahulu. Dalam kajian ini, jalur daripada Landsat 5 TM telah digunakan untuk menghasilkan kombinasi nisbah yang berbeza bagi menentukan diskriminasi litologi yang terdapat di dua pulau yang terletak di hujung selatan kepulauan Langkawi, iaitu Pulau Dayang Bunting dan Pulau Tuba. Kedua-dua pulau tersebut mempunyai persamaan daripada segi unit litologi iaitu batu kapur/marmar (Permian Silur-Ordovisi), granit dan alluvium. Terdapat dua formasi yang membentuk batu kapur/marmar di kawasan kajian iaitu Formasi Chuping yang terdiri daripada batu kapur/marmar dan yang kedua ialah Formasi Setul, terdiri daripada bukan sahaja batu kapur/marmar malah terdapat juga perselangan antara dua detrital. Kombinasi nisbah berbeza yang diperoleh daripada penyelidik terdahulu dan yang dihasilkan dalam kajian ini diuji ke atas imej Pulau Dayang Bunting dan Pulau Tuba untuk mengenal pasti kombinasi nisbah terbaik yang mampu membezakan litologi berlainan di kedua-dua pulau. Sejumlah 28 kombinasi telah dijalankan untuk mengkaji kombinasi mana yang paling berkesan. Daripada gabungan 28 nisbah jalur, tiga telah dikenal pasti sebagai yang paling sesuai; 4/3 5/2 3/1, 5/3 4/3 4/1 dan 4/2 5/3 4/3 dalam turutan RGB. Kombinasi ini dipilih kerana menunjukkan perbezaan yang ketara bagi membezakan litologi di kawasan tersebut. Selain itu, tekstur litologi juga membantu dalam membezakan unit litologi yang lain.

Kata kunci: Diskriminasi litologi; gabungan nisbah jalur; Landsat TM; Langkawi; respons spektrum

INTRODUCTION

The advancements in remote sensing technology to acquire the geological aspect of the earth's surface have been of great benefit to geologists who study geological structures, lithology discrimination, geohazard identification and mitigation, geomorphology and landform processes, and mineral exploration (Ali et al. 2012; Mshiu 2011; Mulder et al. 2011; Rouskov et al. 2005; Tofani 2013; van der Meer et al. 2012). In the field of remote sensing, digital image processing has been defined as the creation of modified images that contain more information to assist the visual interpretation of features by manipulating remotely sensed data (Ali et al. 2012). In the literature, Landsat and ASTER images have been widely manipulated and utilized for rock-type geological structure mappings, geohazard identification, land surface temperature, and the exploration of minerals (Gad & Kusky 2006; Lim et al. 2012; Madani 2014; Sabins 1999; Shahabi et al. 2012;

Sultan et al. 1987; Wilford & Creasy 2002; Won-In & Charusiri 2003).

In this study, an investigation on how remotely sensed data are able to assist in lithological discrimination has been tested on the Dayang Bunting and Tuba Islands, located southeast of Langkawi Island, Malaysia (Figure 1). The study area covers approximately 67 km^2. The rock units in the Dayang Bunting and Tuba Islands are part of the larger rock formations that cover parts of the Langkawi main island and have been the subject of studies in different geological fields, such as geological structure and stratigraphy, geomorphology and geological conservation (Abdullah 1989, Abdullah & Sarman 1999; Jones 1981; Komoo 2002, 1999).

The Dayang Bunting and Tuba Islands consist of two rock formations, specifically the Setul and Chuping Formations (Juhari 1999). The Setul Formation (Ordovician to Devonian) is dominated by dolomitic limestone with alternating layers of clastic rocks, such as shale and mudstone (Leman 2010). In addition to shale and mudstone, metamorphic rock (slate and quartzite) is also present in the Setul Formation (Juhari 1999). The Chuping (Permian to Triasian) Formation, however, is primarily composed of limestone and marble. Juhari (1999) noted that the occurrence of marble on the island is caused by the intrusion of granite in the northern and eastern sections of the island. Alluvium and peat (swamp) are located in the north and southeast of Dayang Bunting Island and at the center (next to the granite rock unit) of Tuba Island. A geological map of the Dayang Bunting and Tuba Islands, with the fault separating the Setul and Chuping Formations, is shown in Figure 2.

The characteristics of the different lithological units and how they differ in spectral response in remotely sensed data has not been thoroughly studied in the study area and the presence of thick vegetation may also complicate the image interpretation; therefore, this research focused on how to improve image interpretation of the study area by using ratio image processing applied to a Landsat TM image, which also can be used to study the different landforms of the lithologies (Manap et al. 2010).

MATERIALS AND METHODS

The Landsat 5 TM images used in this study were acquired on the 26th of February 1996. This date was selected because the images contained a minimal amount of cloud cover. The study area was located in the scene numbers (path/row) 128/056 and 129/056 in the Landsat TM index data. Several digital processes were needed to prepare the images for analysis and interpretation. Digital image processing can be categorized into two categories (Ali et al. 2012): first, the pre-processing of a satellite image involves correcting the geometry and radiometry of the raw satellite image; then, mosaicking and sub-setting of the image is performed to obtain the area of interest. Subsequently, image enhancement procedures were applied to the image so that useful information can be extracted.

PRE-PROCESSING PROCESSING

To rectify the image geometry, a high resolution SPOT 5 (2.5 m pan-sharpened) satellite image was used. To properly georectify the Landsat 5 images, 30 ground control points (GCP) in the SPOT 5 image were selected as references. The number of control points chosen is considered to be acceptable in this study compared to the size of the study area. In this geo-rectification process, it was quite difficult

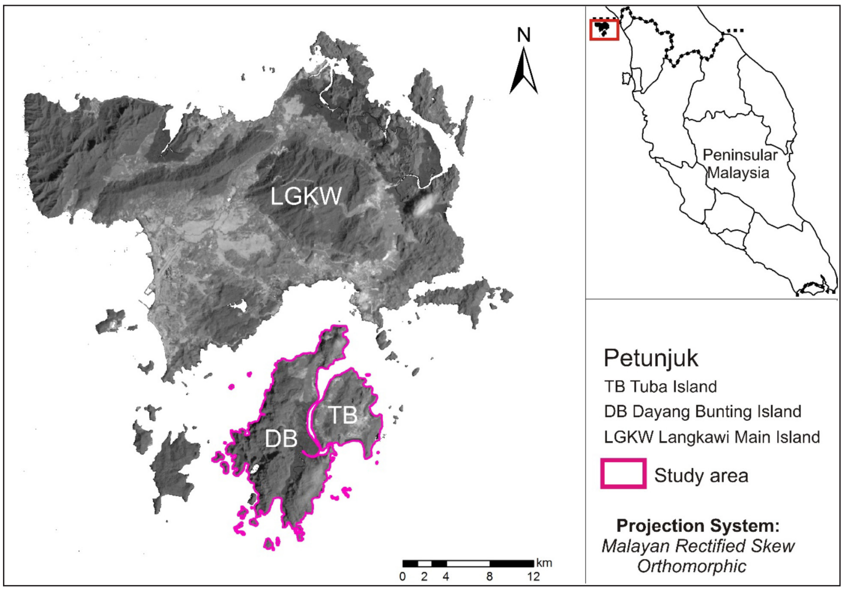

FIGURE 1. The location of the study area (Dayang Bunting and Tuba islands) which is located to the south of the Langkawi main island

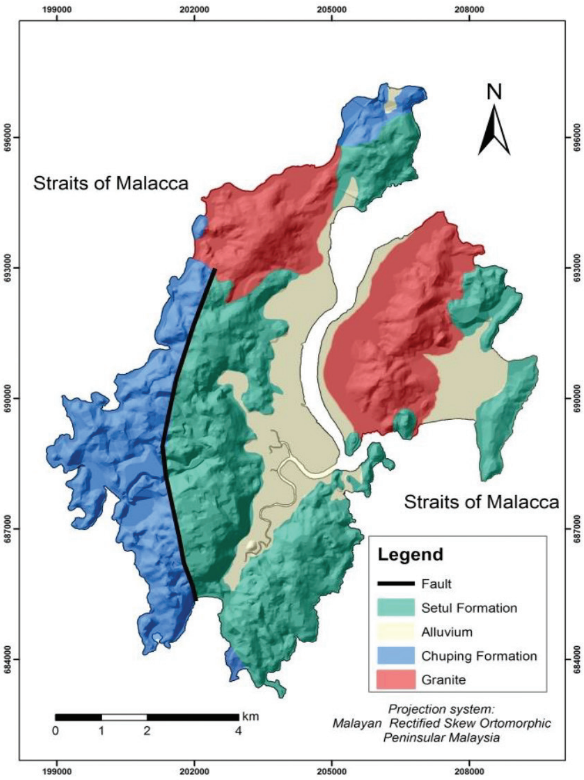

FIGURE 2. A geological map of the Dayang Bunting and Tuba Islands of Langkawi (modified from Jones 1981)

to identify man-made structures as the reference points in both images due to the date differences and the fact that these islands are conserved for their geoforest status. Therefore, natural shapes, such as meandering rivers, hilltops, sharp edges and rugged terrain, were used as the reference points. To prevent mismatches, the total RMS error that resulted from the processing was consistently checked, and the final total RMS error from the geo-rectification process using the spline transformation was 0.006. Both of the Landsat 5 TM images were later mosaicked.

IMAGE ENHANCEMENT PROCESSING

Image enhancement should be applied only after the image undergoes geometric and radiometric corrections (Ali et al. 2012). The type of image enhancement technique that was applied in this research is the band ratio technique. Several authors have shown the ability of the band ratio technique to enhance the spectral response of different minerals and rocks (Ali et al. 2012; Mshiu 2011; Sabins 1999; Sultan et al. 1987). The image underwent contrast stretching and histogram equalization to increase its interpretability before the band ratio processing was conducted.

In this study, the Landsat 5 TM bands were de-layered into their individual bands, 1, 2, 3, 4, 5, and 7, using ArcGIS 10.1 software. After the delayering process, the band ratio processing began. The process begins by dividing between the bands. Then, the ratio bands were compared to identify which ratio band had the highest amount of geological information. This was accomplished by assessing the contrast, brightness, and tonal variation of each band. For comparison, a total of 30 ratios representing each individual band were created (Table 1). The ratios that contain greater geological information were used later in the analysis.

After the ratios in Table 1 were selected, these ratios were manipulated in the RGB guns to determine the best ratio combinations that could effectively distinguish between different lithological units in the Dayang Bunting and Tuba Islands. A combination of different band ratios from Table 1 will be used to discriminate the different lithologies in the study area. The experimented combination in the RGB sequence is presented in Table 2.

Apart from the ratio combinations produced in this study, several combinations that have been suggested and proven by other researchers to be effective in discriminating different lithologies and minerals will also be applied to the image. These combinations were applied to both Landsat TM and ETM+, as suggested by different researchers (Table 3). Although there are differences in the sensors used to create the ratio by different researchers, the wavelength for the bands used by both the TM and ETM+ sensors remained the same (Table 4) and apart from the wavelength, both sensors also have a high degree of similarity in terms of their radiometric and geometric properties (Vogelmann et al. 2001).

TABLE 1. The individual band image ratio produced in this study for the selection of the best individual bands, which are later used in the band ratio combination

	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
Band 1		2/1	3/1	4/1	5/1	7/1
Band 2	1/2		3/2	4/2	5/2	7/2
Band 3	1/3	2/3		4/3	5/3	7/3
Band 4	1/4	2/4	3/4		5/4	7/4
Band 5	1/5	2/5	3/5	4/5		7/5
Band 7	1/7	2/7	3/7	4/7	5/7	

TABLE 2. The 19 band ratio combinations generated from this study

Band Ratio Combinations in RGB Sequence				
1/2 1/3 1/4	2/1 2/3 2/4	3/1 3/2 3/4	4/1 4/2 4/3	5/2 5/3 5/4
1/2 1/3 1/6	2/1 2/3 2/6	3/13/4 3/6	4/2 4/3 4/5	5/3 5/4 5/6
1/3 1/4 1/5	2/1 2/4 2/5	3/2 3/4 3/5	4/3 4/5 4/6	6/1 6/2 6/3
1/4 1/5 1/6	2/4 2/5 2/6	3/4 3/5 3/6	5/1 5/2 5/3	

TABLE 3. Suggested ratio combinations from the literature applied to the Dayang Bunting and Tuba Islands' Landsat TM image

Researcher	Suggested combination	Sensor used
Bishta (2009)	5/7 5/1 4/1	Landsat EMT+
Gad & Kusky (2006)	5/3 5/1 7/5	Landsat TM
Gad & Kusky (2006)	7/5 5/4 3/1	Landsat EMT+
Mshiu (2011)	1/3 5/7 3/5	Landsat TM
Ciampalini et al. (2012)	3/1 5/7 5/4	Landsat EMT+
Ciampalini et al. (2012)	5/7 3/1 4/3	Landsat EMT+
Sadek & Hassan (2012)	7/4 3/7 4/5	Landsat EMT+
Ali et al. (2012)	5/7 5/1 (5/4*3/4)	Landsat EMT+
Madani (2014)	7/3 7/2 5/2	Landsat ETM+

TABLE 4. The wavelengths for bands 1, 2, 3, 4, 5, and 7 found in the Landsat 5 TM and Landsat 7 ETM+ images are the same

Band	Electromagnetic spectrum	Wavelength (μm)	Resolution (m)
Band 1	Blue – green	0.45 – 0.52	30
Band 2	Green	0.52 – 0.61	30
Band 3	Red	0.63 – 0.69	30
Band 4	Infrared	0.76 – 0.90	30
Band 5	Infrared	1.55 – 1.75	30
Band 7	Infrared	2.08 – 2.35	30

Source: adapted from USGS (2013)

Results & Discussion

SPECTRAL COLOR

A total of 28 combinations, which include nine suggested combinations from various studies, were applied to the image. The combinations obtained from previous studies were from Ali et al. (2012), Bishta (2009), Ciampalini et al. (2012), Gad & Kusky (2006) and Sadek and Hassan (2012). These band ratio image combinations were shown in Figure 3.

Based on the different combinations, it appears that the combination of RGB (5/3 5/1 7/5) by Gad and Kusky (2006) is better than the other suggested combinations. The aforementioned combination enhances the topography relief texture as well as the spectral color of each lithology, enabling each to be distinguished. The combination noticeably displays the different textures of limestone, granite and alluvium. However, in terms of lithological discrimination, the spectral reflectance by the different lithologies obtained from this ratio combination is not

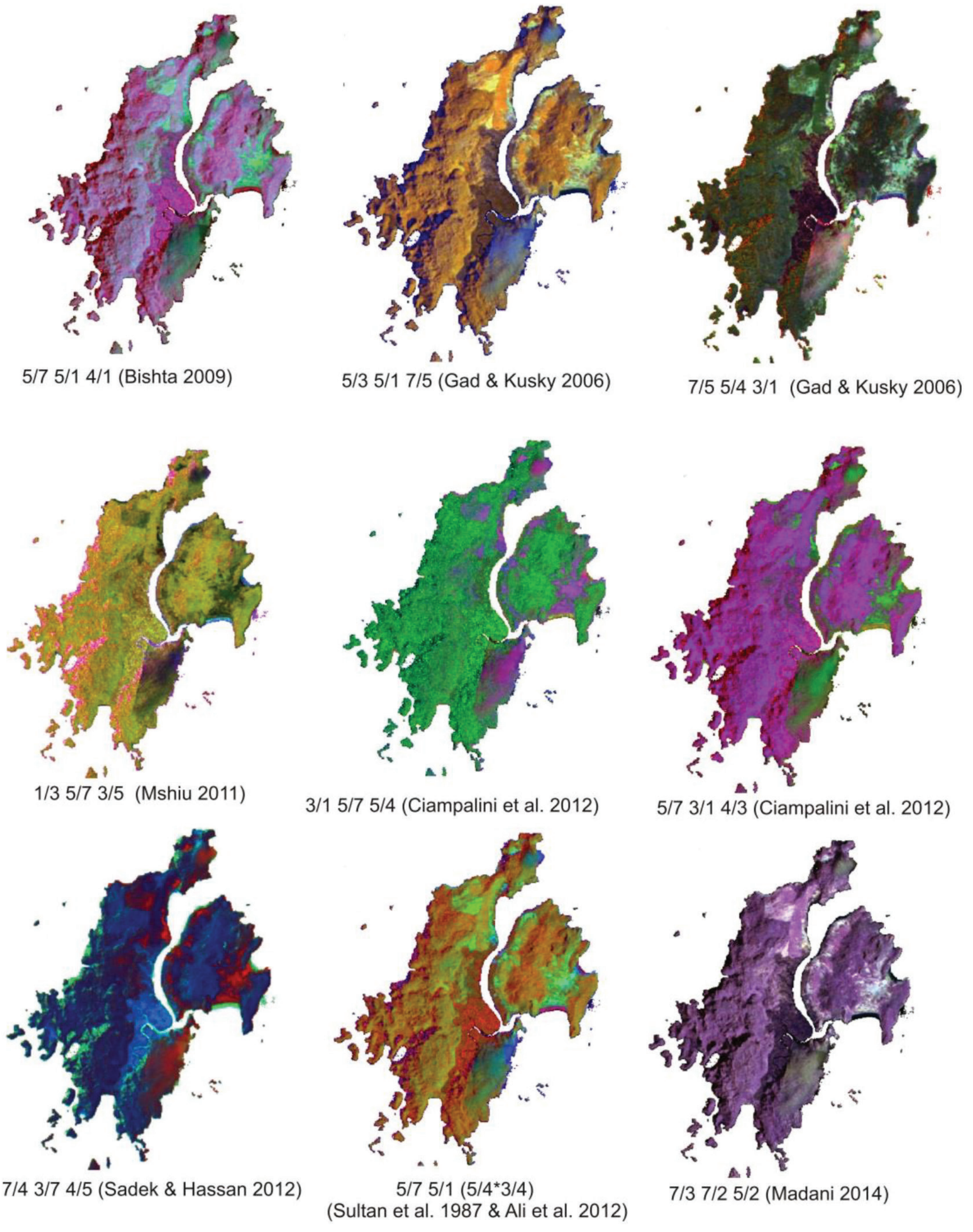

FIGURE 3. Band ratio combinations from previous researcher applied to the Landsat 7 ETM+ image of Dayang Bunting Island

efficient enough. As shown in Figure 4, the limestone/marble and granite lithologies have a similar spectral reflectance. Only the alluvium area has a distinct spectral reflectance, different from the other two units. The same also applies to the ratio combination suggested by Madani (2014), where textural information can be extracted for the different lithologies but cannot be discriminated based on their spectral reflectance.

As for the 19 band ratio combinations produced in this study, three combinations apparently have better discrimination elements. The three ratio combinations are: 4/2 5/3 4/3, 4/3 5/2 3/1 and 5/3 4/2 4/1 in the RGB sequence. In addition to their capability to enhance the spectral reflectance of the different rock types, the texture of each rock type is also observable and clearly displayed for interpretation. The three band ratio combinations with their respective images are shown in Figure 5. From the selected images, the spectral colors representing each of the lithologies were extracted and are shown in Figure 6. Based on this distinctive spectral color, the different units are more easily distinguished. All three combinations show that the swamp area has a much brighter color than

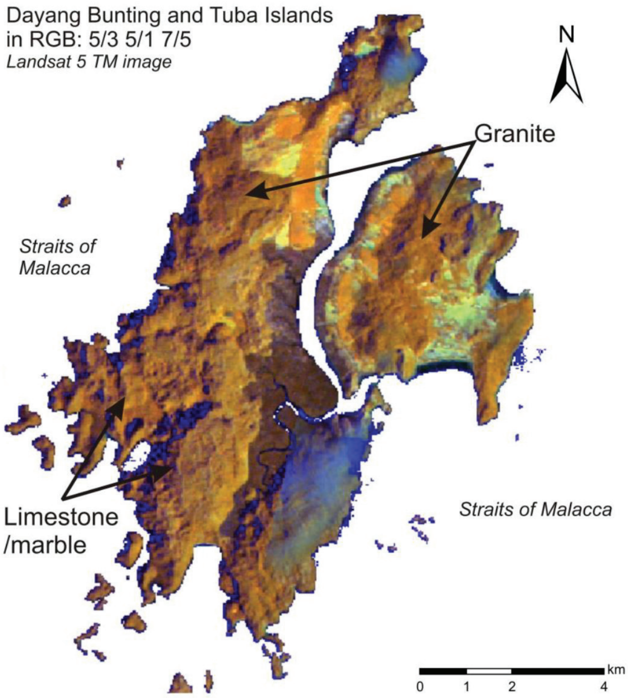

FIGURE 4. Rock texture is clearly visible in this combination (5/3 5/1 7/5) published by Gad and Kusky (2006); however, the limestone/marble and granite lithologies cannot be discriminated based on their spectral reflectance

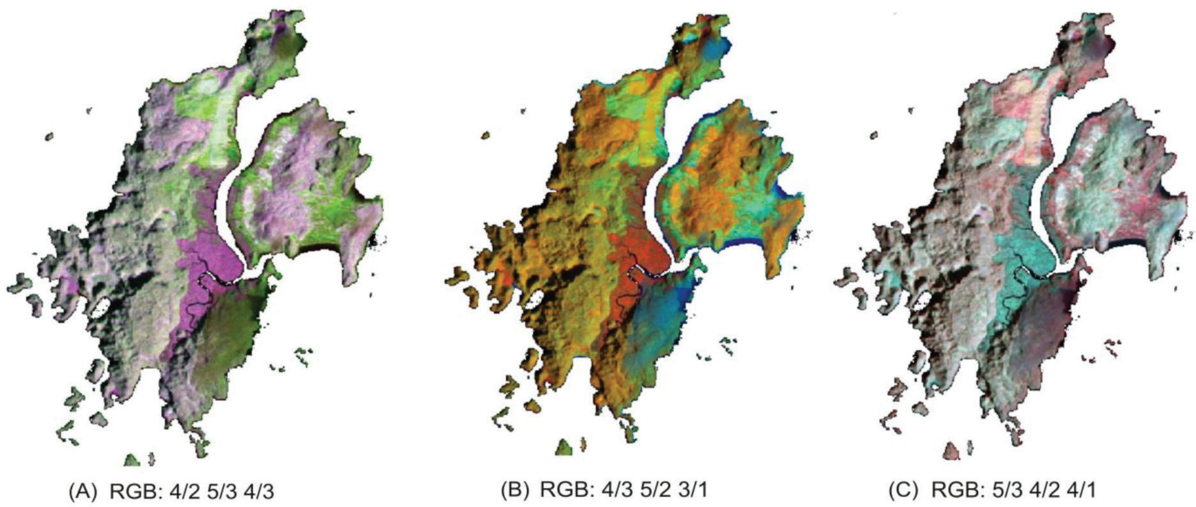

FIGURE 5. The three band ratio combinations that have a better performance than the other 32 combinations produced in this study

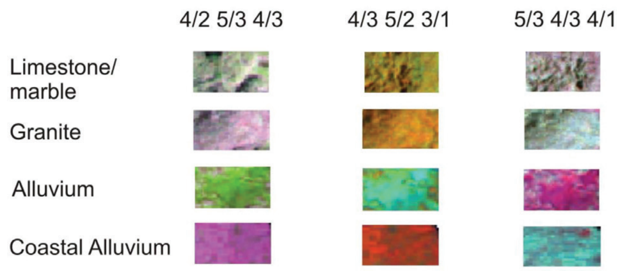

FIGURE 6. Distinctive spectral colors and tones for the different lithological units found in each of the selected images (Figure 5)

the other units. This is followed by the brighter color of the alluvium unit, except in the 5/3 4/2 4/1 combination, where the alluvium has a dark reddish appearance. The granite and limestone/marble have a similar spectral color, but differences are noticeable based on the brighter tone in granite. For example, in the 4/2 5/3 4/3 combination, the granite unit has a brighter, mottled purplish tone than the limestone/marble unit. The same is true for the 4/3 5/2 3/1 combination, where granite has a brighter, orange-brown tone than the greenish-brown limestone/marble unit.

ROCK TEXTURE

The discussion of the rock texture is based on the appearance of the different lithological units in relation to the different rock formations as indicated in the geological map in Figure 2. Based on the geological map there are two formations, specifically the Chuping and Setul Formations, which have similar lithologies (limestone/marble) and are separated by a fault in the SW direction. By using the 4/2 5/3 4/3 combination, the different textures of the two formations can be distinguished. The Setul Formation has a smoother surface and appears to have a higher elevation than the limestone bodies in the Chuping Formation. The presence of clastic material might be the reason why the Setul Formation has a higher resistance to dissolution, which led to more rounded hills and a higher elevation than the Chuping limestone formation. Compared to the Setul Formation, the Chuping Formation has a rougher texture due to the active dissolution of limestone. This active dissolution is indicated by the presence of mogote and doline, which are common in the Chuping Formation. The granite lithology is found in the northern part of Dayang Bunting Island and in the middle of Tuba Island. The texture of this rock is smooth and the rounded hills

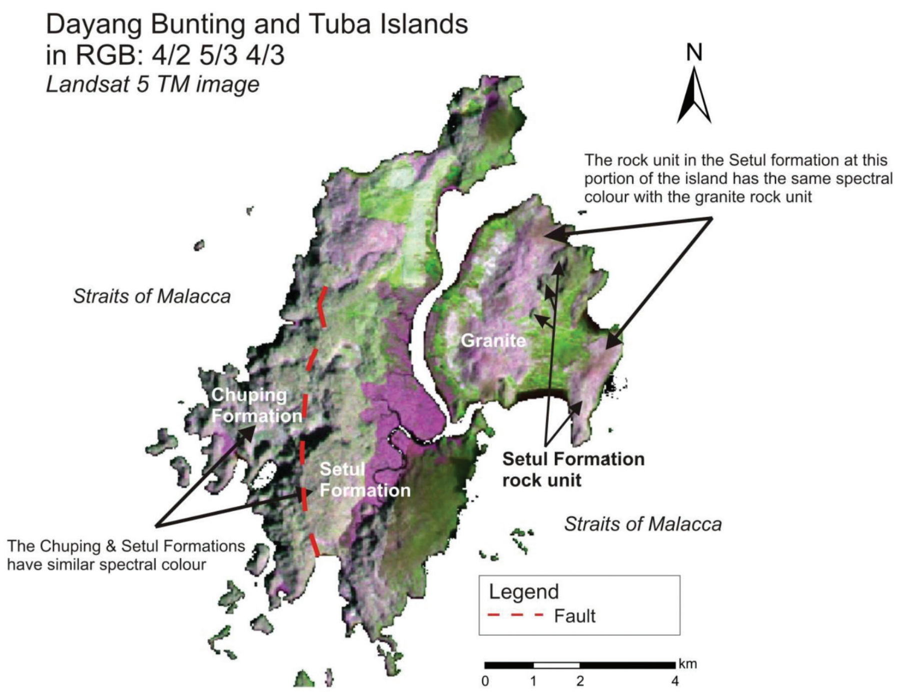

FIGURE 7. Similarity in spectral color between the Chuping and Setul Formations due to their similar lithologies

are obvious. The alluvial and swamp areas have flat and smooth surfaces. These two units are easily distinguished by their spectral color followed by their smooth and flat surfaces.

BAND RATIO COMBINATION ISSUES

The first issue with the band ratio combinations encountered in this study is the similarity of the spectral colors and tones of the lithological units in the different rock formations (Figure 7). Therefore, using the spectral color alone to separate the rock units for the different rock formations can be quite challenging. Another issue is the rock texture between the Setul Formation and the granite bodies on Tuba Island. The Setul Formation on the eastern part of Tuba Island has a similar topography and texture with the granite body on the same island. The presence of a higher clastic material in the Setul Formation might have caused this condition. However, although there are similarities in both the spectral response and texture appearances in the different rock formations, the combination of rock textures, knowledge of the geomorphology of different rock types, and spectral response can help to minimize the level of difficulties in distinguishing the different lithologies in this study; thus, the issue of spectral and textural similarities became insignificant.

CONCLUSION

The band ratio image enhancement technique applied on the Landsat 5 TM image of the Dayang Bunting and Tuba Islands permits the discrimination of different lithologies. Three band ratio combinations produced in this study demonstrate a better discrimination of different rock types than the other 25 combinations. In addition to displaying a different spectral response, these combinations also enhance the textural information of the different lithologies, which can indirectly be used to assist in the discrimination of different lithologies for each of the rock formations.

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