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IDENTIFICATION OF MANGROVE FORESTS USING MULTISPECTRAL SATELLITE IMAGERIES

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Abstract. The visual identification of mangrove forests is greatly constrained by combinations of RGB composite. This research aims to determine the best combination of RGB composite for identifying mangrove forest in Segara Anakan, Cilacap using the Optimum Index Factor (OIF) method. The OIF method uses the standard deviation value and correlation coefficient from a combination of three image bands. The image data comprise Landsat 8 imagery acquired on 30 May 2013, Sentinel 2A imagery acquired on 18 March 2018 and images from SPOT 6 acquired on 10 January 2015. The results show that the band composites of 564 (NIR+SWIR+Red) from Landsat 8 and 8a114 (Vegetation Red Edge+SWIR+Red) from Sentinel 2A are the best RGB composites for identifying mangrove forest, in addition to those of 341 (Red+NIR+Blue) from SPOT 6. The near-infrared (NIR) and short-wave infrared (SWIR) bands play an important role in determining mangrove forests. The properties of vegetation are reflected strongly at the NIR wavelength and the SWIR band is very sensitive to evaporation and the identification of wetlands.

Keywords: *Mangrove, OIF, Landsat 8, Sentinel 2A, SPOT 6, Combinations*

1 INTRODUCTION

The existence of mangrove forests in coastal areas is very important because of the many benefits they provide for other ecosystems. Mangrove forests are a common form of coastal vegetation in tropical and sub-tropical coastal areas. They are influenced by sea tides and are capable of adapting to brackish environments. Nybakken (1982) stated that mangrove forests is a general term used to describe a variety of tropical beach communities dominated by several species of distinctive trees or shrubs that are able to grow in saltwater. In addition, mangroves grow on sheltered or flat beaches, usually alongside islands in areas protected from the wind or behind coral reefs off sheltered shorelines. Some of the functions and benefits of mangrove forests include their ability to protect coastal stability from abrasion, seawater intrusion, storm surges, maintenance of the natural habitat, as areas for the spawning and growth of various species of fish, shrimp, shellfish, birds and other fauna, and land-forming. Mangrove forest can also be utilised for conservation, education and ecotourism (Setyawan *et al.*, 2006). Mangrove forest grows well around the Segara Anakan lagoon, Cilacap. The calm water supports this location as one of the areas with the greatest mangrove potential in Java (Ardli, 2008).

Remote sensing technology has been used to identify the distribution of mangrove forests since their presence inland and in sea transition areas produces a distinctive spectral reflection compared to other objects (Faizal & Amran, 2005). The spectral values derived from remote sensing satellite images can be extracted to provide

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mangrove type object information in the range of visible and near-infrared (NIR) spectra (Suwargana, 2008).

Landsat 8 imagery can be used to detect mangrove forests. This type of satellite imagery is medium-resolution and is an evolution of the mission of the previous Landsat 7 (ETM +) satellite. The advantage of Landsat imagery is the existence of an NIR band that can help in the identification of mangrove forests. Purwanto *et al.* (2014) used Landsat 8 imagery to map the mangrove forests in Segara Anakan, Cilacap, achieving a result accuracy rate of 82.05%. Setiawan *et al.* (2015), meanwhile, used Landsat 8 imagery when mapping the mangrove forest in Muara Gembong, Bekasi.

Sentinel-2 involves two remote sensing satellites with passive sensors that were launched in 2015 and 2017 as part of the Copernicus European Space Agency (ESA) programme. The Sentinel 2A satellite launched as part of this mission generates imagery with a spectral resolution consisting of 13 channels that include visible sensors, NIR and short-wave infrared (SWIR). Its spatial resolution is regarded as quite high, at 10 metres for the red, blue, green and NIR bands, in addition to 6 bands with a resolution of 20 m, and 3 bands with a spatial resolution of 60 m. It has a field of view of 290 km (Kawamuna *et al.*, 2017). Sentinel 2A imagery has been widely used in a range of different applications, including analysis of land cover and land-use change, disaster mitigation, agriculture, forestry, environmental monitoring and urban planning. Wachid *et al.* (2017) mapped mangrove canopy density using Sentinel 2A imagery in Teluk Jor, Lombok Timur Regency, Indonesia using regression analysis between field data hemispherical photography and the subjective density method.

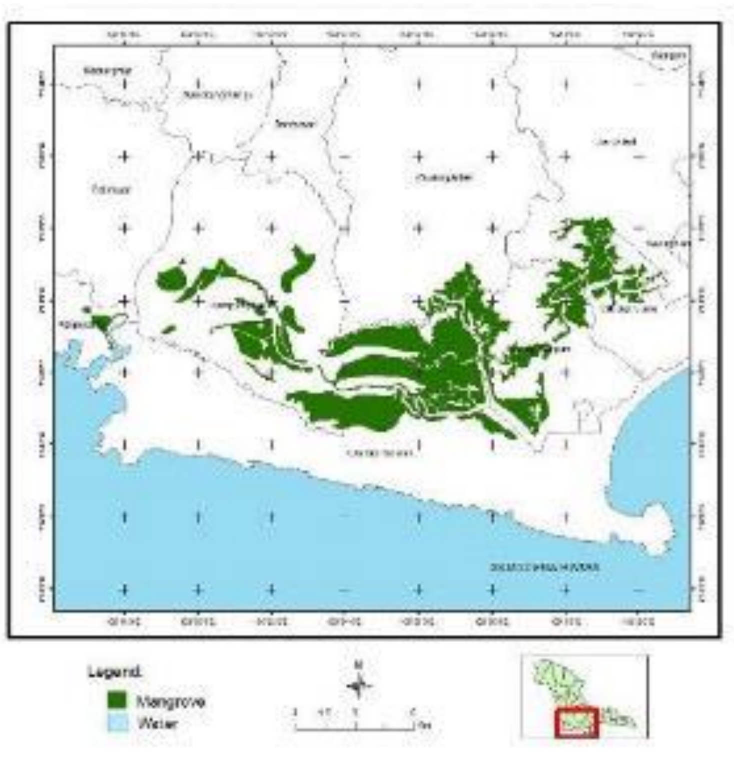


Figure 1-1: Map of the research area (source: Spatial Planning Map of Cilacap District 2011-2031).

The SPOT 6 satellite was launched in India on 9 September 2012. SPOT 6 is a continuation of the previous mission undertaken by the SPOT satellite series and is also the first SPOT-generation satellite to feature a blue spectral channel, meaning it can more clearly identify coastlines, sedimentation and coral reefs (Pustekdata, 2015). SPOT 6 imagery has very good potential for mangrove mapping. Rudiastuti *et al.* (2018) mapped mangrove canopy density using SPOT 6 imagery in East Lombok, Indonesia, achieving in excess of 85% accuracy.

According to Marini *et al.* (2015), visual interpretation of mangrove using remote sensing satellite imagery can be achieved through the proper selection of RGB composites; however, the process requires a considerable amount of time due to the many potential combinations of the 3 (three) composite bands. Thus, the need exists for a fast and easy method of identifying mangrove forest. One such method is the Optimum Index Factor (OIF) which uses statistical calculations to determine the appropriate combination of 3 (three) bands in the image that will yield the optimal and most informative colour display (Chavez *et al.,* 1982). The higher the OIF value of the selected band combination, the more information (high standard deviation) with less 'duplication' (low correlation values between bands) it conveys. To this end, each of the selected three-band colour composites can be evaluated for their effectiveness. The OIF method of determining the best RGB composites with which to identify mangrove forests has been widely used by researchers. For example, Manoppo *et al.* (2015) employed OIF in their research to identify mangrove forest using SPOT 6 and Landsat 8 imagery in Lingayan Island, while Marini *et al.* (2015) used 6 bands (band 2 to band 7) on Small Subi Island.

This study aims to determine the best band combination for identifying mangrove forests in Segara Anakan, Cilacap from multispectral satellite imageries (Landsat 8, Sentinel 2A and SPOT 6) using the OIF method.

2 MATERIALS AND METHODOLOGY

2.1 Location and Data

This research was conducted in the Segara Anakan area, Cilacap Regency, Central Java province with the coordinate limitations of 7°37'22"-7°47'37" LS and 108°45'11"-109°2'54" BT. The satellite imageries used in this study were Landsat 8 Path 121 Row 065 image acquisition dated 30 May 2013, Sentinel 2A image acquisition dated 18 March 2018 and SPOT 6 image acquisition dated 10 January 2015. Table 2-1 contains a comparison of the band specifications of Landsat 8, Sentinel 2A and SPOT 6. The mangrove distribution data used in this study were obtained from field measurements taken between 2013 and 2015 in Segara Anakan, Cilacap. Segara Anakan itself is a lagoon located on the southern coast of Java Island in an area that forms part of Cilacap Regency, Central Java. Nusakambangan Island stands in front of this area and stretches for approximately 30 kilometres in an east-west direction, protecting the bay from the waves of the Indian Ocean. Most of the Segara Anakan area comprises of lowlands dominated by mud and waterways such as the estuary of the Citandui river, the Donan river and the Cibereum river, with the coastal areas overgrown with mangrove forests. The calm water gives this area some of the highest mangrove potential in Java. Figure 1-1 contains a map of the mangrove distribution in Segara Anakan, Cilacap as the research area

Table 2-1: Band specifications of Landsat 8 OLI/TIRS (https://landsat.usgs.gov/sites/default/files/documents/Landsat8DataUsersHandbook.pdf), Sentinel 2A (Zhang *et al.*, 2018) and SPOT 6 MS (Jhonnerie, 2015).

LDCM OLI/TIRS		**SENTINEL 2A**		**SPOT 6 MULTISPECTRAL**	
Band	**Central Wavelength**	**Band**	**Central Wavelength**	**Band**	**Central Wavelength**
Band 1	Coastal/Aerosol, (0.443 μm), 30 m	Band 1	Coastal Aerosol, (0.443 μm), 60 m	Band 1	Blue, (0.485 μm), 6 m
Band 2	Blue, (0.482 μm), 30 m	Band 2	Blue, (0.490 μm), 10 m	Band 2	Green, (0.560 μm), 6 m
Band 3	Green, (0.561 μm), 30 m	Band 3	Green, (0.560 μm), 10 m	Band 3	Red, (0.660 μm), 6 m
Band 4	Red, (0.655 μm), 30 m	Band 4	Red, (0.665 μm), 10 m	Band 4	NIR, (0.825 μm), 6 m
Band 5	Near-Infrared, (0.865 μm), 30 m	Band 5	Vegetation Red Edge, (0.705 μm), 20 m		
Band 6	SWIR 1, (1.609 μm), 30 m	Band 6	Vegetation Red Edge, (0.740 μm), 20 m		
Band 7	SWIR 2, (2.201 μm), 30 m	Band 7	Vegetation Red Edge, (0.783 μm), 20 m		
Band 8	Pan, (0.590 μm), 15 m	Band 8	NIR, (0.842), 10 m		
Band 9	Cirrus, (1.373 μm), 30 m	Band 8A	Vegetation Red Edge, (0.865 μm), 20 m		
Band 10	LWIR 1, (10.895 μm), 100 m	Band 9	Water Vapour, (0.945 μm), 60 m		
Band 11	LWIR 2, (12.005 μm), 100 m	Band 10	SWIR-Cirrus, (1.375 μm), 60 m		
		Band 11	SWIR, (1.610 μm), 20 m		
		Band 12	SWIR, (2.190 μm), 20 m		

2.2 Methods

The number of band combinations was determined using the following equation:

$$\binom{N}{3} = \frac{N!}{(3! * (N-3)!)} \qquad (2\text{-}1)$$

where:
N = The total number of bands in the map list

Interpretation of the mangrove forest can be made using an image colour composite to sharpen the appearance of the vegetation elements (Pusfatja, 2015). We used the *OIF* method (Chaves *et al.,* 1982) to determine the best three-band composite as follows:

$$OIF = \sum_{i=1}^{3} SDi \Big/ \sum_{j=1}^{3} ABS(CCj) \qquad (2\text{-}2)$$

where:
SDi = Standard deviation of band i
ABS =Absolute value of 3-band correlation coefficient

Figure 2-1: Distribution of training samples of mangrove

The identification of mangrove forests using a spatial approach was performed by observing the appearance of the canopy texture and location (Danoedoro, 2009). It is also based on two important properties, namely the mangrove forest growing in coastal areas and the chlorophyll content of leaves that absorbs the red spectrum and strongly reflects the infrared spectrum (Susilo, 2000). Leaves have green characteristics, where chlorophyll absorbs the spectrum of red and blue and reflects the green spectrum (Lo, 1996). The intensity of the reflection depends on the wavelength used and the three vegetation components, i.e. leaves, substrate and shadow. Leaves reflect weakly at the blue and red wavelengths but strongly at the NIR wavelength. The characteristic green colour of leaves means the chlorophyll absorbs the red and blue electromagnetic spectrum and reflects the spectrum of green radiation. The highest OIF value is the result between the highest standard deviation divided by the lowest correlation coefficient of the band combination used. The standard deviation and correlation coefficients are obtained by delineating some regions as areas of mangrove forest (Figure 2-1).

The OIF method uses the total value of the standard deviations divided by the correlation coefficient of the three selected bands. Before calculating the OIF value, it is necessary to determine the number of three-band combinations from each image using the existing equations. The number of combinations (N) resulting from Landsat 8 imagery stands at 35, Sentinel 2A has 20 combinations and the SPOT 6 imagery has 4 combinations.

3 RESULTS AND DISCUSSION

3.1 OIF Calculation of Landsat 8 OLI

OIF calculations were performed for each of the three-band combinations. The combination of RGB composites with the highest OIF values represents the best combination results. The results of the 35 band combinations for Landsat 8 are shown in Attachment 1. Table 3-1 shows that the correlation coefficient value between band 4 and band 5 is 0.494, the correlation coefficient value between band 4 and band 6 is 0.571 and the correlation coefficient between band 4 and band 7 is 0.59. The total of these three correlation coefficient values is relatively small compared to the totals of the other correlations.

Table 3-1: Correlations between Landsat 8 bands.

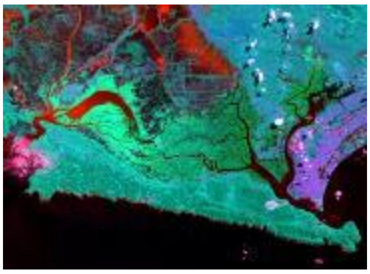
Band	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6	Band 7
Band 1	1						
Band 2	0.983	1					
Band 3	0.909	0.922	1				
Band 4	0.888	0.917	0.83	1			
Band 5	0.715	0.7	0.866	0.494	1		
Band 6	0.683	0.676	0.821	0.571	0.884	1	
Band 7	0.67	0.665	0.795	0.59	0.829	0.993	1

The highest OIF value resulted from a combination of bands 4, 5 and 6. That value is only slightly higher than the band combinations with the second-highest (bands 2, 5 and 6) and third-highest OIF values (bands 1, 5 and 6). The 35 band combinations from Landsat 8 are shown in Table 3-2. Based on Table 3-2, the combination of band 4 (Red), band 5 (NIR) and band 6 (SWIR) has the highest OIF value (OIF=2722.284). Meanwhile, the combination of band 1 (coastal/aerosol), band 2 (blue) and band 4 (red) has the lowest OIF value (OIF=146.513). The combination of bands 4, 5 and 6 has a high standard deviation value and the correlation coefficient value is very low. Thus, the combination of these bands has the highest OIF value. On the other hand, the combination of bands 1, 2 and 4 has the lowest standard deviation; also, the correlation coefficient value is relatively high, which means this band combination has the lowest OIF value. OIF values are generated from the band combinations that are in the range of visible, visible + NIR, visible + SWIR, visible + NIR + SWIR, and NIR + SWIR spectrums. The three best OIF values for identifying mangrove forest are dominated by the visible band, NIR band and SWIR band. This is in line with research by Suwargana (2008) which identified mangrove forests with satellite imagery using band channels in the range of the visible and NIR spectra. In addition, the vegetation properties reflect strongly at the NIR wavelength and absorb the red and blue electromagnetic spectrum and reflect the green electromagnetic spectrum (Lo, 1996). According to Winarso and Purwanto (2017), remote sensing technology plays an important role in the context of mangrove forest habitat where wetland conditions absorb electromagnetic waves in the SWIR spectrum, meaning that the use of the band 6 (SWIR) electromagnetic spectrum is optimal for mangrove identification. It was also confirmed in this study that all three of the highest OIF values for Landsat 8 use band 5 (NIR) and band 6 (SWIR). The RGB composite for natural colour in Landsat 8 imagery is 432 where all the bands are in the range of the visible electromagnetic spectrum. Based on the OIF calculations, the combination of natural colour bands from Landsat 8 imagery is ranked 32 with an OIF value 214.903, meaning it is not optimal for use in identifying mangrove forest because in principle the natural colour composite produces the actual colour of the object on the earth surface.

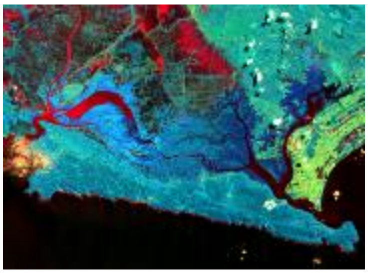
Table 3-2: OIF values of Landsat 8.

Band combinations	Sum of standard deviations	Sum of correlation coefficient of bands	OIF	Rank
456	5,305.731	1.949	2722.283	1
256	5,270.418	2.26	2332.043	2
156	5,257.317	2.282	2303.819	3
457	4,389.251	1.913	2294.433	4
356	5,422.416	2.571	2109.068	5
567	5,621.112	2.706	2077.277	6
257	4,353.938	2.194	1984.474	7
157	4,340.837	2.214	1960.630	8
145	4,025.456	2.097	1919.626	9
345	4,190.555	2.19	1913.495	10
245	4,038.557	2.111	1913.101	11
357	4,505.936	2.49	1809.612	12
235	4,155.242	2.488	1670.113	13
125	3,990.143	2.398	1663.946	14
135	4,142.141	2.49	1663.510	15
246	1,688.752	1.488	1134.913	16
467	2,039.446	2.154	946.818	17
267	2,004.133	2.334	858.668	18
167	1,991.032	2.346	848.692	19
346	1,840.750	2.222	828.420	20
367	2,156.131	2.609	826.420	21
146	1,675.651	2.142	782.283	22
236	1,805.437	2.419	746.356	23
136	1,792.336	2.413	742.783	24
126	1640.338	2.342	700.400	25
347	924.270	2.215	417.277	26
237	888.957	2.382	373.197	27
137	875.856	2.374	368.936	28
247	772.272	2.172	355.558	29
147	759.171	2.148	353.431	30
127	723.858	2.318	312.276	31
234	573.576	2.669	214.902	32
134	560.475	2.627	213.351	33
123	525.162	2.814	186.624	34
124	408.477	2.788	146.512	35

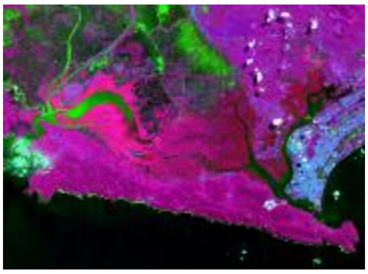
For example, vegetation appears as green, sea is blue and so on. Natural colour composite makes it more difficult to distinguish between mangrove forest and non-mangrove objects due to the limitations of the electromagnetic spectrum channel used. The NIR and SWIR bands play an important role in distinguishing mangroves from the surrounding objects. Both bands affect colour visualisation. If the red and blue channels are placed by the NIR and SWIR bands, the display will be dominated by magenta colours. Meanwhile, if the NIR and SWIR bands are placed in the green and blue channels, the colours will be dominated by cyan. The best position is for the NIR and SWIR bands to be placed on the red and green channels, which gives the mangrove a reddish colour. However, if the NIR and SWIR bands are placed on the green and red channels, then the NIR band provides natural colour information that is green.



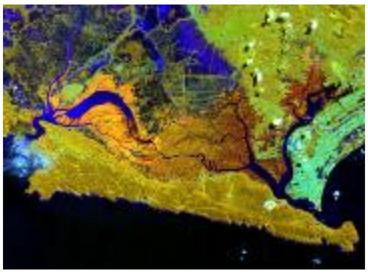
Rank 1 -
RGB Composite 456



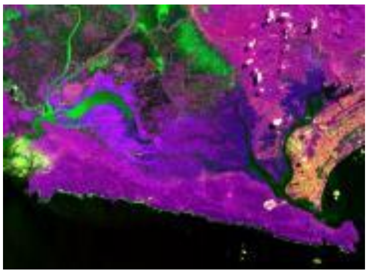
Rank 1 -
RGB Composite 465



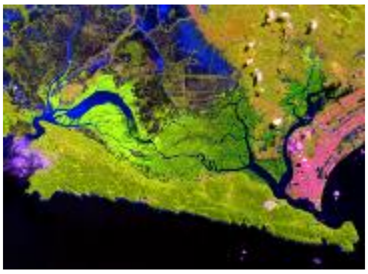
Rank 1 -
RGB Composite 546



Rank 1 -
RGB Composite 564



Rank 1 -
RGB Composite 645



Rank 1 -
RGB Composite 654

Figure 3-1: Composite results for Bands 4, 5 and 6 with the highest OIF values.

The composite results for bands 4, 5 and 6 are shown in Figure 3-1.

The visual interpretations of mangrove forest in Figure 3-2 reveal that the RGB 564 composite has the best appearance and is more informative compared to the other RGB composites, while RGB 546 shows all vegetation in a magenta colour. The reflectance of NIR is the highest compared to the red band, thus indicating that the position of the NIR band greatly determines the display of colour.

The visual appearance of the RGB 564 composite is similar to that of the RGB 567 composite because the red and green channels of the two composites use the NIR band and the SWIR 1 band. The blue channel of the RGB 564 composite uses the red band but the RGB 567 composite uses the SWIR 2 band, which means that water appears differently in the two composites (water in the RGB 564 composite is blue, while in the RGB 567 composite it is black).

Mangrove forest is displayed with a reddish-brown colour, deep water is black, shallow water is blue, vegetation is shown in a green colour and rice fields are indicated in dark green. Mangrove forest is also identified based on its texture and location on the beach (Susanto & Asriningrum, 2011). The RGB 564 composite was used for interpretation of the mangrove forest, which included the three bands in the range of the visible and NIR spectrum.

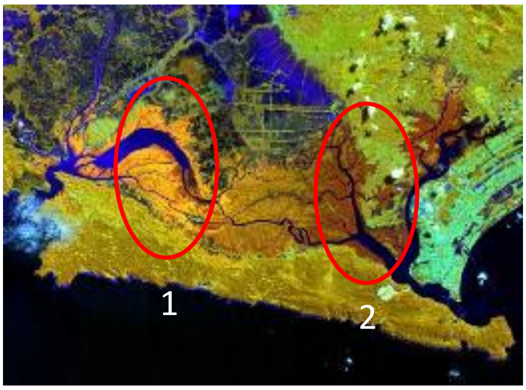
Figure 3-2 contains a comparison of the False Colour and True Colour RGB composites derived from the Landsat 8 imagery. The false colour is a combination of several bands on the satellite imagery that allows us to obtain spatial information on the satellite image. The natural colour, meanwhile, is the actual colour found on the surface of the earth. The natural colour consists of band 1 shown in blue, band 2 shown in green and band 3 shown in red. The RGB 564 composite appears more optimal in terms of distinguishing between mangrove forest and other objects, compared to the RGB 432 composite. The mangrove forest contrasts with other vegetation and land and waters objects. The reddish colour indicates a relatively higher intensity of water conditions compared to the lighter colours. The RGB 564 composite, as one of the band combinations with the highest OIF values, indicates the appropriate colour for identifying mangrove and non-mangrove objects. This shows that the SWIR 1 band is important for identifying mangrove both visually and digitally. The RGB 432 composite shows vegetation in a relatively homogeneous colour, which makes it difficult to distinguish the mangrove forest from other vegetation. Figure 3-3 indicates the differences in appearance between the two RGB composites, notably showing the composition of existing mangrove where the RGB 564 composite (false colour) is able to distinguish between major mangrove and minor mangrove distribution. In contrast, it is very difficult to distinguish between major and minor mangrove distribution in the RGB 432 composite (natural colour).

The results have similarities with the OIF research conducted by Manoppo et al. (2015) where RGB composite 564 from a Landsat 8 image had the highest OIF value for identifying mangrove forests in Lingayan Island, Central Sulawesi (Figure 3-3). The results of other OIF research conducted by Marini et al. (2015) in Subi Kecil Island, Riau revealed RGB composite 573 of a Landsat 8 image to have the highest OIF value (Figure 3-4). The difference in the RGB composite result from Subi Kecil Island is due to the difference in land cover.

Subi Kecil Island is a small island surrounded by shallow water and a relatively small mangrove area. This research area (Segara Anakan, Cilacap) meanwhile contains a river estuary and is also affected by the tidal flow from the sea. The left side of the research area contains association mangrove (derris trifoliata and acanthus ilicifolius), while the right side is true mangrove (genus of rhizopora, bruguiera and sonneratia). The central section contains Nypa mixed with Ceriops Tagal.

3.2 OIF Calculation of Sentinel 2A

Identification of mangrove forests was also carried out using Sentinel 2A imagery. One of the advantages of Sentinel 2A imagery is the relatively large number of bands (multispectral). There are a total of 13 bands divided into 3 types of spatial resolution (10 m, 20 m and 60 m).



(a)

(b)

Figure 3-2: Comparison of RGB composites, (a) RGB 564 (False Colour), (b) RGB 432 (Natural Colour).

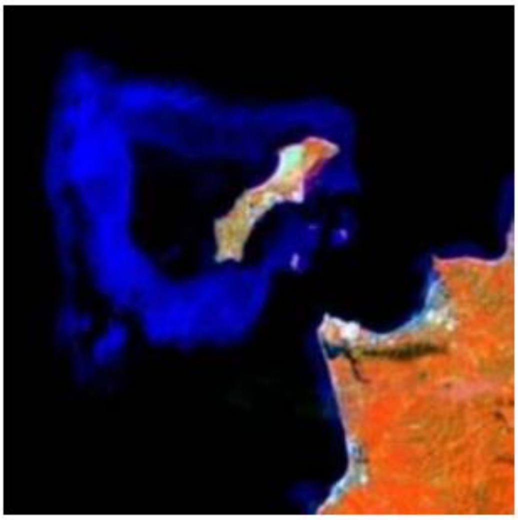


Figure 3-3: Identification of mangroves in Lingayan Island with RGB 564 Landsat 8 (Manoppo *et al.,* 2015).

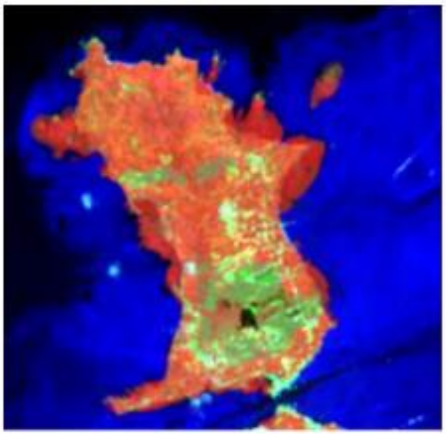


Figure 3-4: Identification of mangroves in Subi Kecil Island with RGB 573 Landsat 8 (Marini *et al.,* 2015).

OIF calculations for identifying mangrove forests using Sentinel 2A images were carried out through two experiments related to the selection of bands used. The initial experiment was conducted by selecting bands with a spatial resolution of 20 m, as previously carried out by Kawamuna *et al.* (2017) who used RGB composite 8a115 to identify mangrove using Sentinel 2A images in Pangpang Bay, Banyuwangi. The other experiment involved choosing certain bands (up to 6), including band 2 (blue), band 3 (green), band 4 (red), band 5 (vegetation red edge), band 8a (vegetation red edge) and band 11 (SWIR). Bands for spectral vegetation are only used in bands 5 and 8a, whereas SWIR bands used only band 11. The use of 6 bands, namely band 2 (blue), band 3 (green), band 4 (red), band 5 (vegetation red edge), band 8a (vegetation red edge) and band 11 (SWIR) showed optimal and effective results and proved capable of clearly distinguishing mangrove forest objects.

The amount of duplication between band combinations can be identified from the correlation coefficient values of each band. Table 3-3 shows the correlation between bands for the Sentinel 2A imagery. From the calculation of the total correlation between band 4, band 8a and band 11, we can see there is a relatively low correlation value. A low correlation indicates a low duplication of information from the combination of the bands.

Table 3-3: Correlation between Sentinel 2A bands

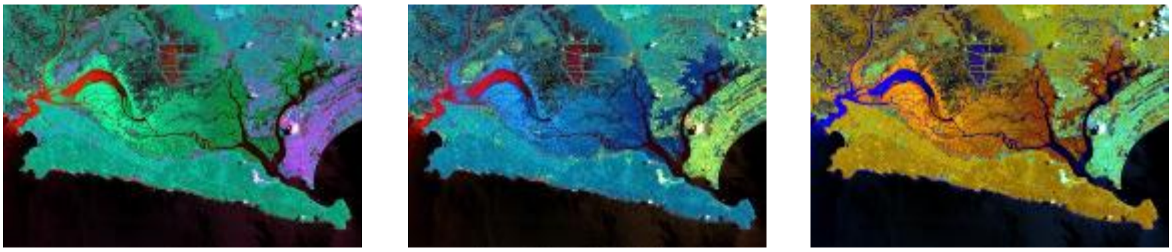
	Band 2	**Band 3**	**Band 4**	**Band 5**	**Band 8a**	**Band 11**
Band 2	1					
Band 3	0.856	1				
Band 4	0.851	0.632	1			
Band 5	0.677	0.899	0.473	1		
Band 8a	0.607	0.779	0.271	0.755	1	
Band 11	0.738	0.834	0.473	0.803	0.906	1

The results of the combination of the 20 bands from Sentinel 2A are shown in Table 3-4. Meanwhile, the results of the RGB composite appearance for each combination are shown in Attachment 2.

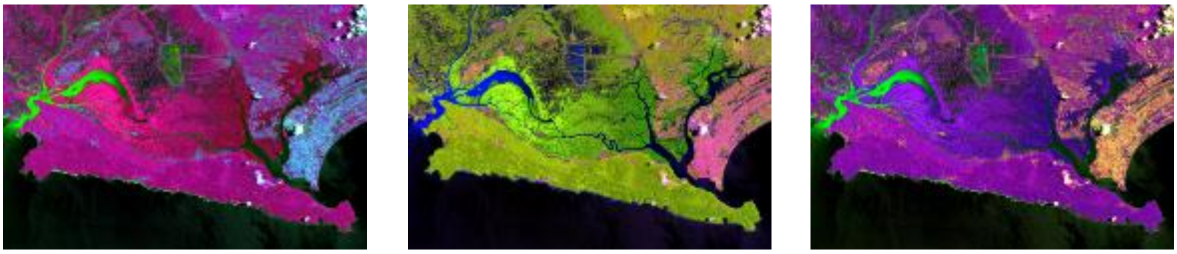
Figure 3-5 shows the composite results for the combination of bands 4, 8a and 11 that have the highest OIF values from Sentinel 2A imagery. The combination of bands 4, 8a and 11 led to the formation of around 6 RGB composites, namely RGB 48a11, RGB 4118a, RGB 8a114, RGB 8a411, RGB 118a4 and RGB 1148a. From the six RGB composites, RGB 8a114 (vegetation red edge+swir+red) has an excellent display for identifying and distinguishing mangrove forest objects from surrounding objects, where the mangrove forests are displayed in a reddish-brown colour. Similar to the results of the OIF calculations of Landsat 8, the Vegetation Red Edge band (band 8a) of Sentinel 2A with a mid-wavelength of 0.865 μm greatly affects the colour visualisation produced. The best position is band 8a and the SWIR bands (band 11) placed on the red and green channels, which are able to give the mangrove a reddish colour. If the red and green channels are placed by band 8a and the SWIR band, this produces a more uniform colour which makes it difficult to distinguish the mangroves from their surroundings.

Table 3-4: Highest OIF values and ranks of the combinations of Sentinel 2A bands.

Band combinations	**Sum of standard deviations**	**Sum of correlation coefficient of bands**	**OIF**	**Rank**
4, 8a, 11	1465.62	1.65	888.254	1
4, 5, 8a	1161.662	1.499	774.957	2
3, 4, 8a	1148.058	1.682	682.555	3
2, 8a, 11	1452.512	2.251	645.274	4
2, 4, 8a	1093.397	1.729	632.386	5
5, 8a, 11	1520.777	2.464	617.198	6
3, 8a, 11	1,507.173	2.519	598.321	7
2, 5, 8a	1,148.554	2.039	563.292	8
2, 3, 8a	1134.95	2.242	506.222	9
3, 5, 8a	1,203.215	2.433	494.539	10
3, 4, 11	540.906	1.939	278.961	11
2, 5, 11	541.402	2.218	244.094	12
2, 4, 11	486.245	2.062	235.812	13
3, 5, 11	596.063	2.536	235.040	14
4, 5, 11	554.51	2.536	218.655	15
2, 3, 11	527.798	2.428	217.379	16
3, 4, 5	236.948	2.004	118.237	17
2, 3, 5	223.84	2.432	92.039	18
2, 4, 5	182.287	2.001	91.097	19
2, 3, 4	168.683	2.339	72.117	20



Rank 1 - RGB Composite 48a11 | Rank 1 - RGB Composite 4118a | Rank 1 - RGB Composite 8a114

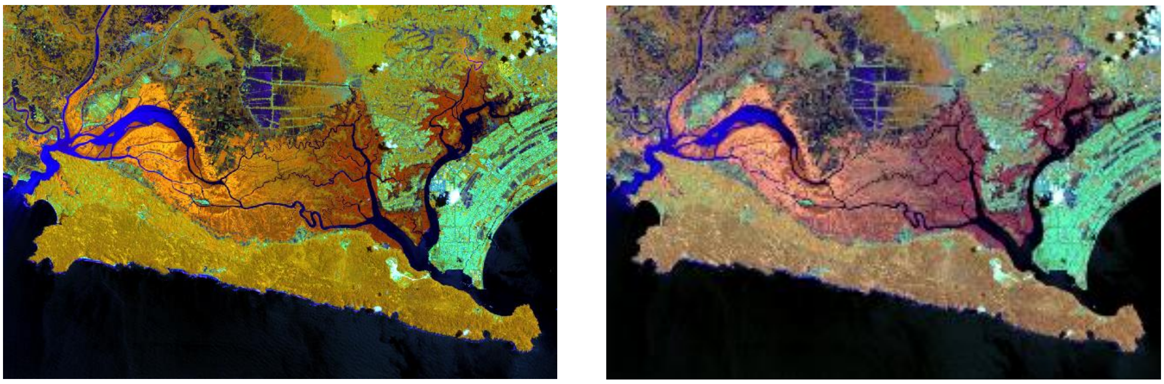


Rank 1 - RGB Composite 8a411 | **Rank 1 - RGB Composite 118a4** | **Rank 1 - RGB Composite 1148a**

Figure 3-5: Composite results for Bands 4, 8a and 11 that have the highest OIF values.

Like the OIF calculation results for Landsat 8, the OIF calculation results from Sentinel 2A also show that the NIR band dominates the band combination of RGB composites with the highest OIF value. The position of the NIR band from the Sentinel 2A image is in band 8a, where the mean wavelength is 0.86 µm. The NIR band is highly optimal for detecting mangrove forest if it is placed on the Red channel and is supported by SWIR band 1 placed on the green channel. The results of RGB 8a114 composite show a clear distinction between the mangrove forest and surrounding objects, while RGB 8a411 composite is less optimal because the blue channel with the input from the SWIR 1 band produces a colour dominated by magenta colours, thus making it difficult to identify the mangrove forests.

The best RGB composite results obtained by this study (RGB 8a114) differ from the RGB composite 8a115 identified by Kawamuna *et al.* (2017), where the difference was found to be in the position of the blue channel placed by the Vegetation Red Edge band. In this study, the blue channel is placed by the Red band. RGB composite 8a114 produces colours that tend to be reddish, while RGB composite 8a115 produces a darker colour (Figure 3-6).



(a) (b)

Figure 3-6: Comparison of (a) RGB Composite 8a114 and (b) RGB Composite 8a115.

3.2 OIF Calculations for SPOT 6

In addition to using Landsat 8 and Sentinel 2A imagery, this research uses imagery from SPOT 6 to identify mangrove forests. Compared to the previous images (Landsat 8 and Sentinel 2A), SPOT 6 imagery has the highest spatial resolution. The images from SPOT 6 have spatial resolutions of 1.5 metres for panchromatic, 6 metres for multispectral and can be used for applications in defence, agriculture, forestry, land cover and land-use change, coastal, engineering, and the oil, gas and mining industries (Pustekdata, 2015). The OIF calculations for identifying mangrove forests used 4 multispectral bands for SPOT 6 images, namely the blue, green, red and NIR bands. A total of 4 RGB combinations were obtained from the four bands, namely combinations of RGB 123, RGB 124, RGB 134 and RGB 234. Table 3-5 shows that the correlation between band 1 and band 4 is 0.015. Meanwhile, the correlation between band 3 and band 4 is -0.115. So, there will be a relatively lower total correlation if the combinations used are band 1 and band 4 or band 3 and band 4. The OIF calculation results are shown in Table 3-6 and the result of the 4 band combinations for SPOT 6 are shown in Attachment 3. The OIF calculations used 4 bands: band 1 (blue), band 2 (green), band 3 (red) and band 4 (NIR). The OIF calculation results reveal the combination of band 1 (blue), band 3 (red) and band 4 (NIR) to have the highest OIF values. Meanwhile, the lowest OIF value is a combination of band 1 (blue), band 2 (green) and band 3 (red).

The combination of SPOT 6's RGB 134 image has the highest OIF value. This combination has a high standard deviation and a low correlation coefficient, thus indicating high diversity with low duplication of information. The correlation values show the magnitude of linear relationships between two variables.

Table 3-5: Correlation between SPOT 6 bands.

Band	Band 1	Band 2	Band 3	Band 4
Band 1	1			
Band 2	0.706	1		
Band 3	0.95	0.651	1	
Band 4	0.015	0.629	0.115	1

Table 3-6: Highest OIF values and ranks of the combinations for SPOT 6.

Band combinations	Sum of standard deviations	Sum of correlation coefficient of bands	OIF	Rank
1, 3, 4	346.814	0.85	408.016	1
2, 3, 4	354.838	1.165	304.581	2
1, 2, 4	354.823	1.35	262.831	3
1, 2, 3	68.837	2.307	29.838	4

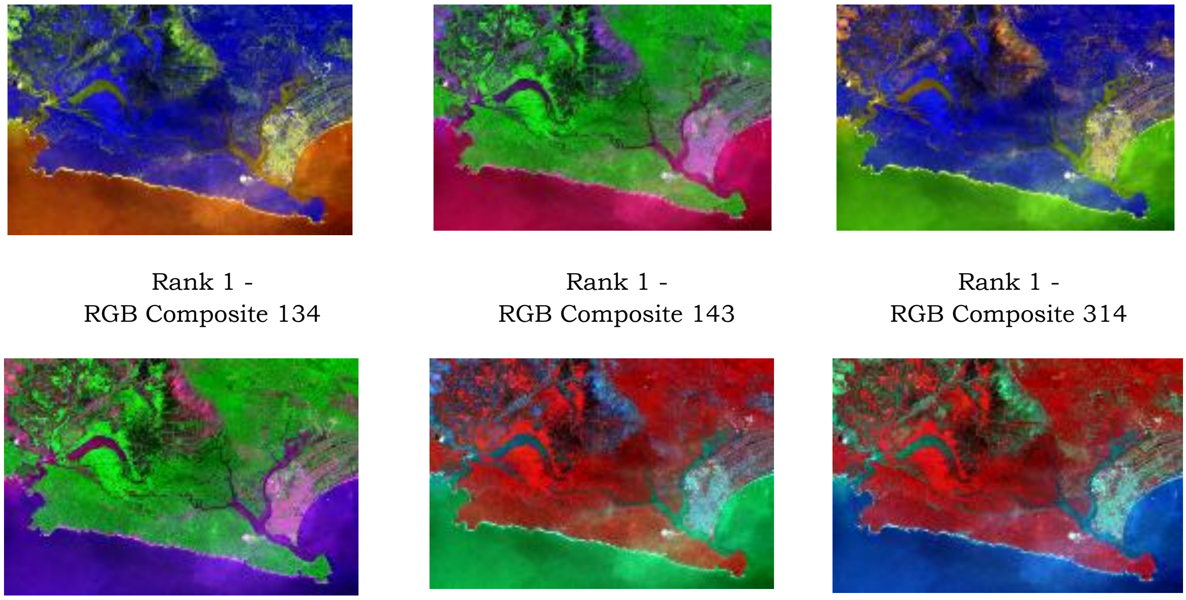
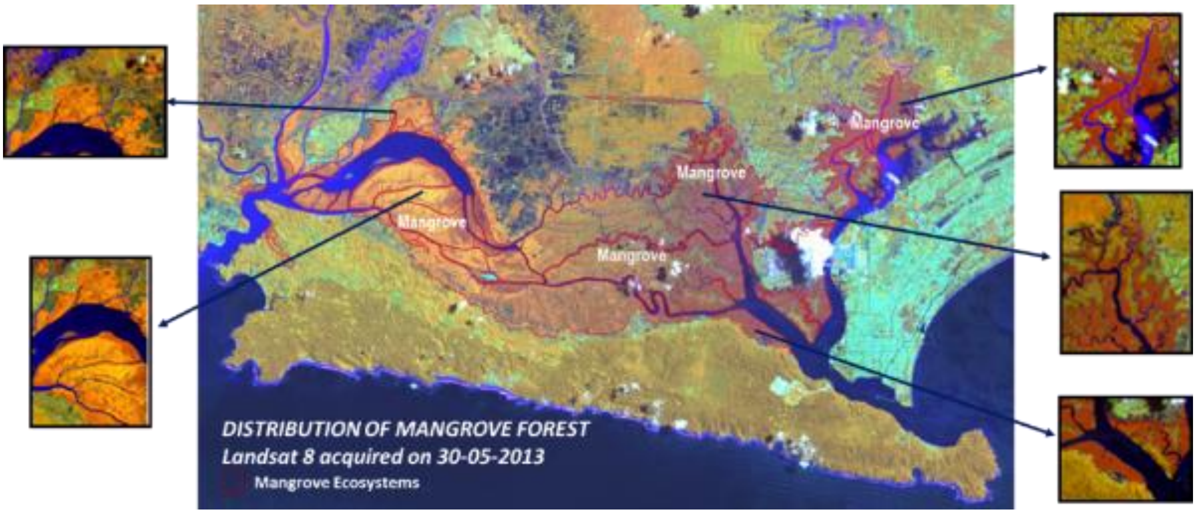


Figure 3-7: Composite results for Bands 1, 3 and 4 that have the highest OIF values.

Figure 3-7 illustrates how mangrove forests are more easily identified using the RGB 341 combination where the mangrove forest appears as a dark green and can be distinguished from the surrounding objects. The RGB 143 combination produces greenish colours for mangrove forest objects but it is very difficult to distinguish objects around the mangroves, with one example being how land and water objects appear in almost the same colour. The identification of mangrove forests using SPOT 6 imagery still requires additional elements of association interpretation, often defined as the relationship between one object and another object, such that one object provides a clue as to the other objects. The association elements used to identify mangrove forests include the presence of marine waters, inland waters (rivers), river estuaries, settlements, land vegetation and others. SPOT 6 imagery does not have a SWIR band, thus meaning it is not optimal to use in identifying mangrove forests compared to Sentinel 2A and SPOT 6 images. SWIR bands are very sensitive to terrestrial objects, which here are inundated mangrove substrates (Winarso & Purwanto, 2017).

3.3 Comparison of the OIF Values for Landsat 8, Sentinel 2A and SPOT 6 Imagery

Figure 3-8 shows a comparison of the best RGB composites derived from Landsat 8, Sentinel 2A and SPOT 6 imagery for identifying the distribution of mangrove forests. The RGB 564 composite from Landsat 8 and RGB 8a114 composite from Sentinel 2A are relatively similar in terms of the appearance of mangrove forests. RGB 341 composite from SPOT 6, meanwhile, is less optimal for detecting mangrove forest. This shows that the existence of the NIR and SWIR 1 band is highly optimal in the detection of mangrove forest. The SPOT 6 imagery does not have an SWIR band, which means it is less optimal in distinguishing mangrove forests, especially in Segara Anakan, Cilacap and requires additional key interpretative associations in order to identify objects around the mangrove forest.



(a)

(b)

(c)

Figure 3-8: Results of the identification of mangrove forests: (a) Landsat 8 imagery (RGB 564), (b) Sentinel 2A imagery (RGB 8a114), (c) SPOT 6 imagery (RGB 341).

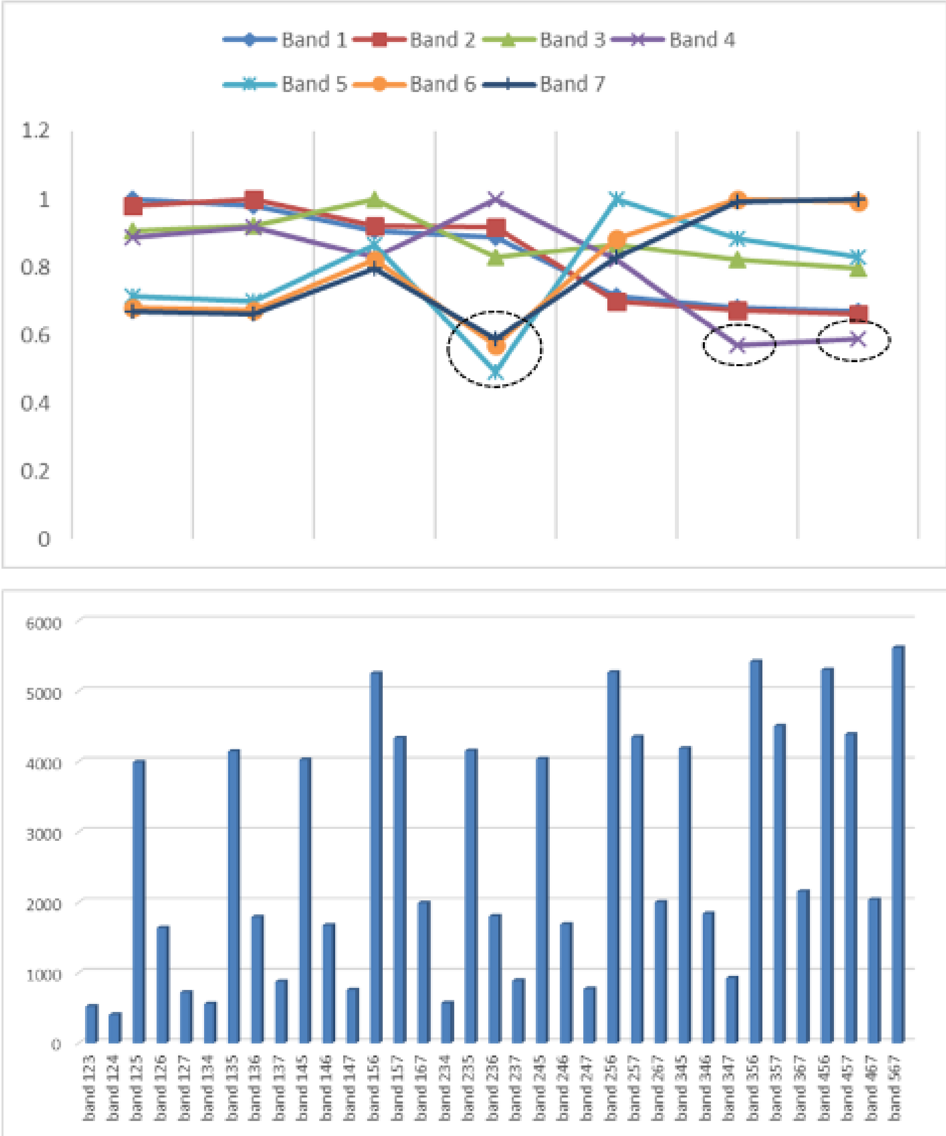


Figure 3-9: Correlation and standard deviation between Landsat 8 bands.

Figure 3-9 shows the band correlation and total standard deviation of Landsat 8 images. From the Landsat 8 imagery, the correlation between band 4 and band 5, band 6 and band 7 is very low. Likewise, the correlation between band 6 and band 7 is relatively low. A list of combinations involving band 4 and band 5 contains two combinations, comprising one of band 4, band 5 and band 6, and the other of band 4, band 5 and band 7. The total correlation between band 4, band 5 and band 6 is 1,949. On the other hand, the total correlation between band 4, band 5 and band 7 is 1,913. The total standard deviation of band 4, band 5 and band 6 is 5,305,731. In the same way, the total standard deviation of band 4, band 5 and band 7 is 4,389,251 (Figure 3-6a). The combination of band 4, band 5 and band 6 has an OIF value higher than the combination of band 4, band 5 and band 7. This is due to the fact that the total standard deviation of band 4, band 5 and band 6 is higher than the total of standard deviation of band 4, band 5 and band 7.

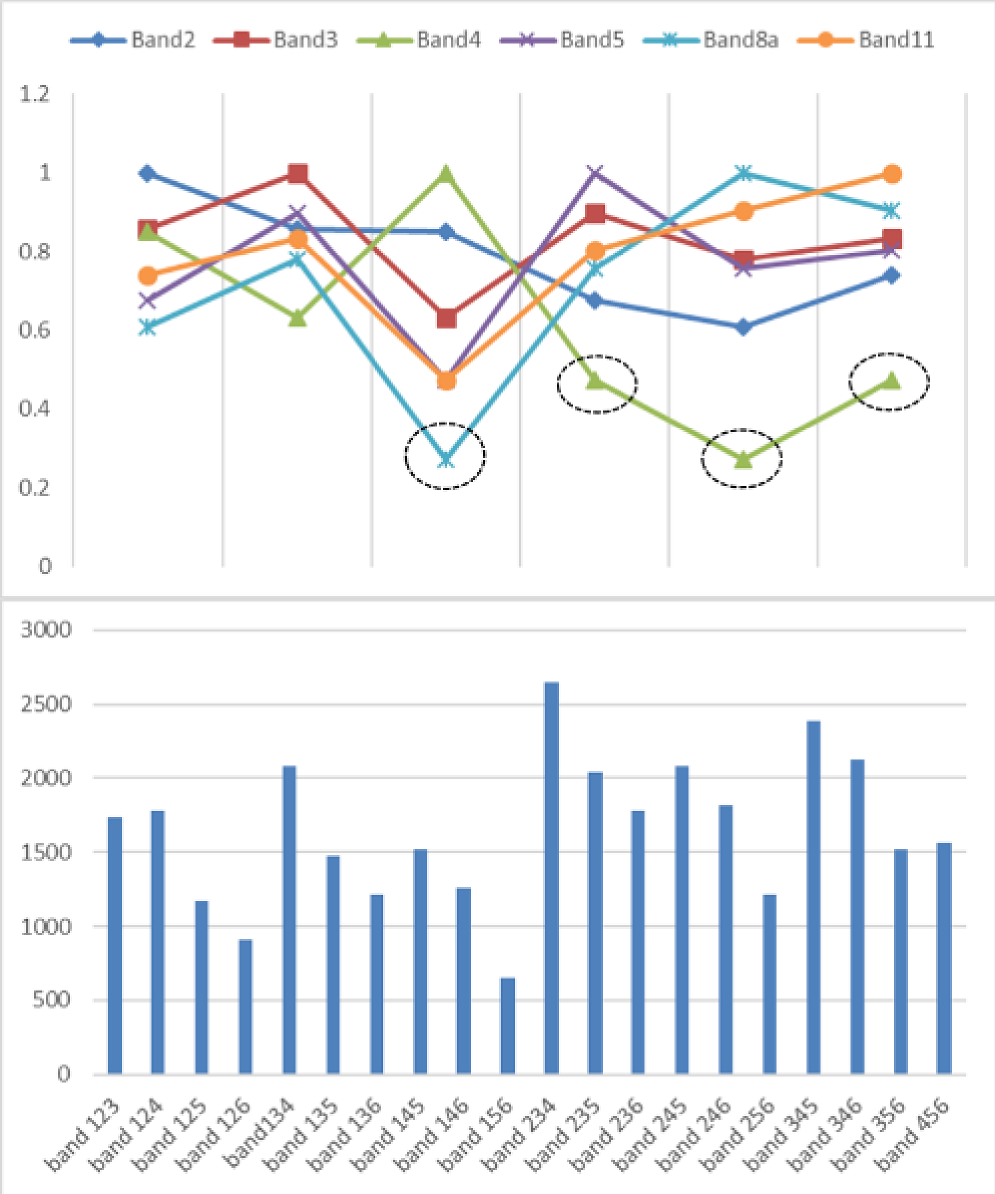


Figure 3-10: Correlation and standard deviation between bands of Sentinel 2A.

Figure 3-10 shows that the lowest correlation for the Sentinel 2A imagery is between band 4 and band 8a. This combination can be formed using two band combinations (a combination of band 4, band 8a and band 11, plus a combination of band 4, band 5 and band 8a). The total of the correlation between band 4, band 8a and band 11 is 1.65. On the other hand, the total of the correlation between band 4, band 5 and band 8a is 1.499. The total standard deviation for band 4, band 8a and band 11 is 1465.62. Meanwhile, the total standard deviation for band 4, band 5 and band 8 is 1161.662. The higher total standard deviation leads to a higher OIF value for the combination of band 4, band 5 and band 8a than that of the combination of band 4, band 5 and band 8.

Figure 3-11 shows that the lowest correlations for the SPOT 6 imagery are those between band 1 and band 4, and band 3 and band 4. This is attained using the three-band combination of band 1, band 3 and band 4, where the combination of the three bands produces a total correlation of 0.85 and a total standard deviation of 408.016. This also has the highest OIF value compared to the other band combinations. Table 3-7 shows a comparison between the RGB composites for mangrove detection in this study with those of previous studies. It can be seen that the optimal wavelength values that provide the best information for identifying mangrove are the red channel (0.865 µm), green channel (1,610 µm) and blue channel (0.650 – 0.820 µm).

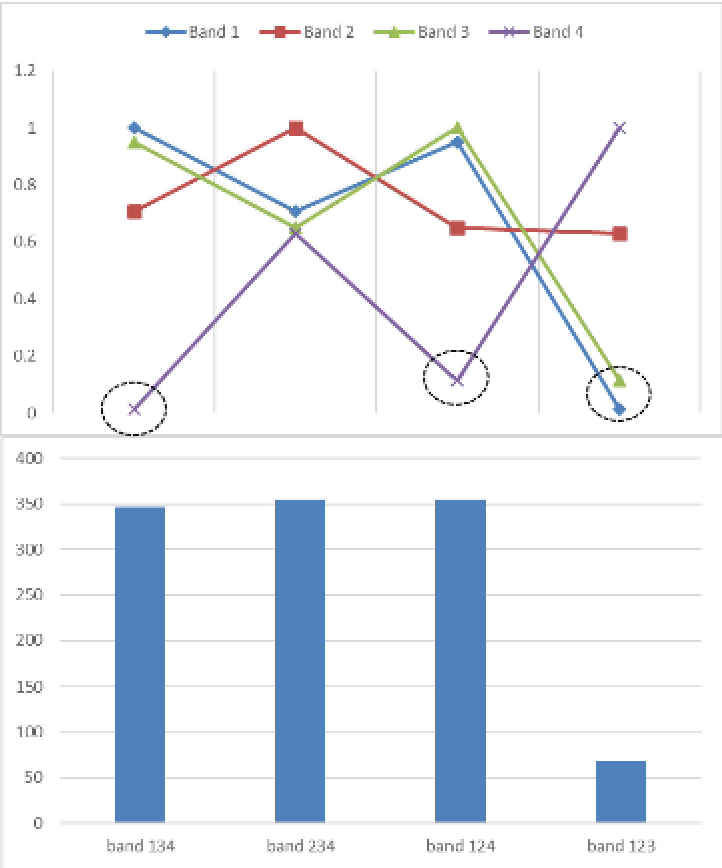


Figure 3-11: Correlation and standard deviation of SPOT 6 bands

Table 3-7: Comparison of RGB composites for mangrove detection

Studies	Red	Green	Blue	Location
		Landsat 8		
Manoppo *et al.* (2015)	Band 5 (~0.865 µm)	Band 6 (~1.610 µm)	Band 4 (~0.650 µm)	Lingayan Island, Central Sulawesi
Marini *et al.* (2015)	Band 5 (~0.865 µm)	Band 7 (~2.200 µm)	Band 3 (~0.565 µm)	Subi Kecil Island, Riau
This study (2019)	Band 5 (~0.865 µm)	Band 6 (~1.610 µm)	Band 4 (~0.650 µm)	Segara Anakan, Central Java
		Sentinel 2A		
Kawamuna *et al.* (2017)	Band 8a (~0.865 µm)	Band 11 (~1.610 µm)	Band 5 (~0.705 µm)	Pangpang Bay, Banyuwangi
This study (2019)	Band 8a (~0.865 µm)	Band 11 (~1.610 µm)	Band 4 (~0.820 µm)	Segara Anakan, Central Java

CONCLUSION

The results have shown that the band composite of 564 (NIR+SWIR+Red) from Landsat 8 imagery and the band composite of 8a114 (Vegetation Red Edge+SWIR+Red) from Sentinel 2A imagery are the best RGB composites for identifying mangrove forest. In the same way, the band composite of 341 (Red+NIR+Blue) from SPOT 6 imagery is also the best colour composite (R-G-B) for identifying mangrove forest in Segara Anakan, Cilacap.

The NIR band with a mean value of 0.86 μm plays an important role in the determination of mangrove forests. The RGB composite from the Landsat 8 and Sentinel 2A imagery shows that the red channel should be placed by the NIR band (0.86 μm), the green channel is placed by the SWIR 1 band (1.6 μm) and the blue channel is placed by the red band (0.65 μm–0.8 μm). The SWIR band is important for determining the RGB composites to use in identifying mangrove forests as it is very sensitive to evaporation and the identification of wetlands.

The RGB composites of images developed from Landsat 8 and Sentinel 2A imagery are capable of distinguishing mangrove forest from the surrounding objects more clearly, although the composite images from SPOT 6 imagery still require additional association elements in order to identify mangrove objects.

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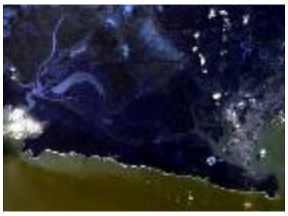
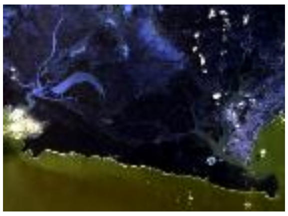
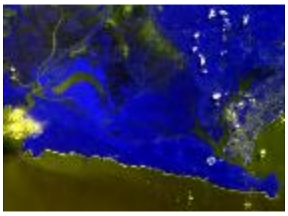
Attachment 1: RGB Composites of Landsat 8 Imagery


RGB 123 - Rank 34


RGB 124 - Rank 35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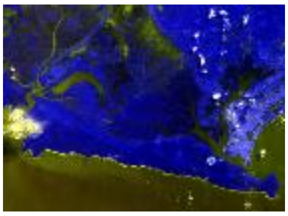
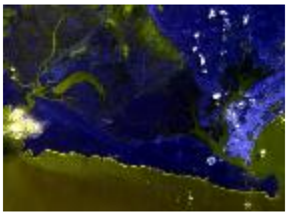

RGB 126 - Rank 25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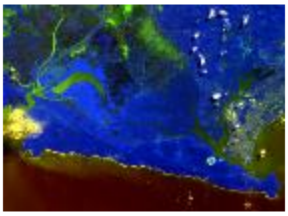
RGB 134 - Rank 33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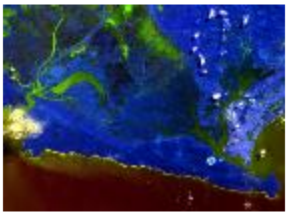
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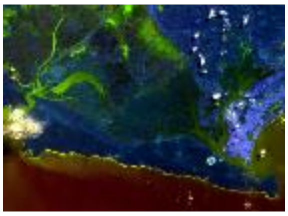
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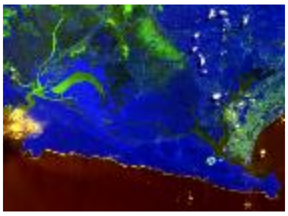
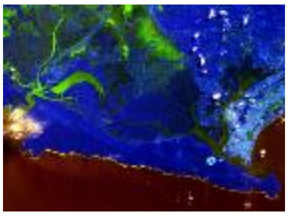
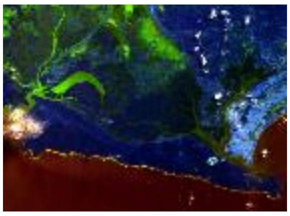
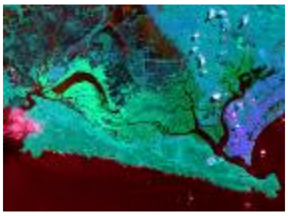
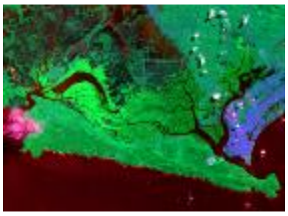
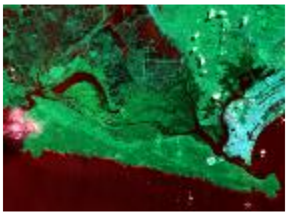

RGB 145 - Rank 9

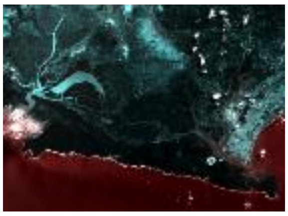

RGB 146 - Rank 22


RGB 147 - Rank 30


RGB 156 - Rank 3


RGB 157 - Rank 8


RGB 167 - Rank 19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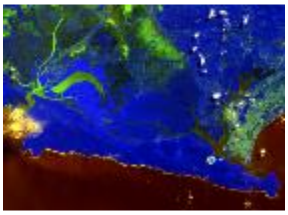
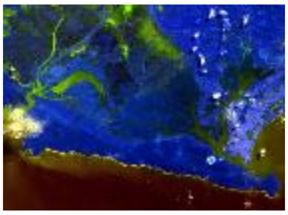

RGB 235 - Rank 13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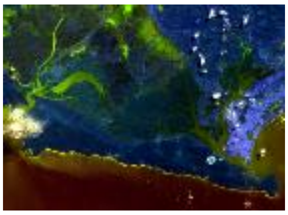
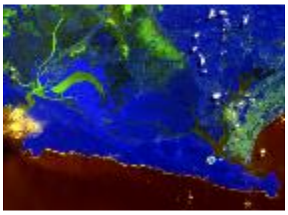
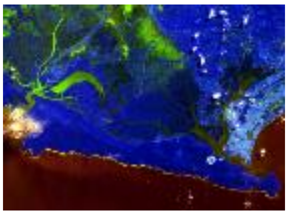
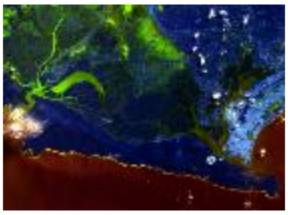
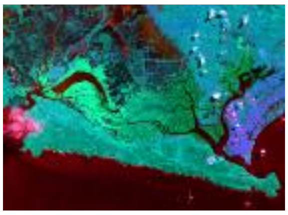
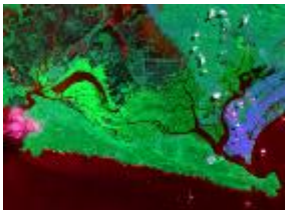

RGB 237 - Rank 27

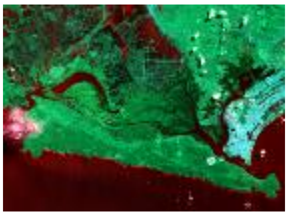

RGB 245 - Rank 11


RGB 246 - Rank 16

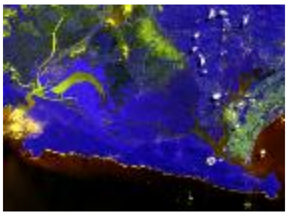

RGB 247 - Rank 29


RGB 256 - Rank 2

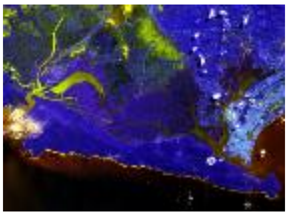

RGB 257 - Rank 7



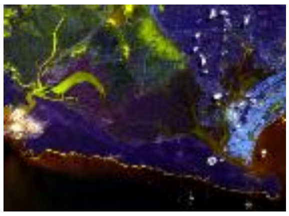
RGB 267 - Rank 18



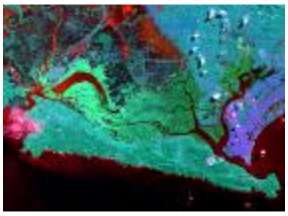
RGB 345 - Rank 10



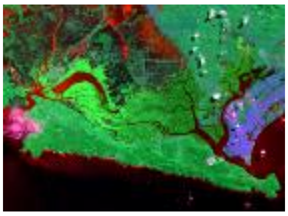
RGB 346 - Rank 20



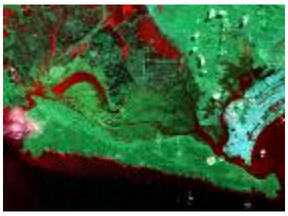
RGB 347 - Rank 26



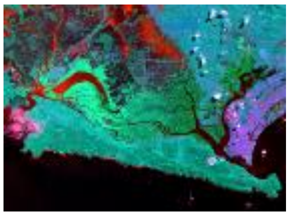
RGB 356 - Rank 5



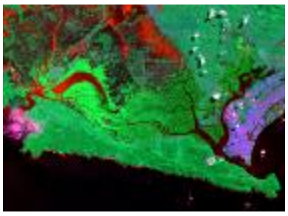
RGB 357 - Rank 12



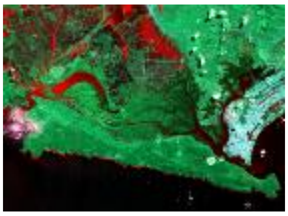
RGB 367 - Rank 21



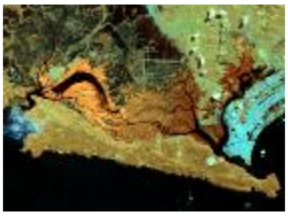
RGB 456 - Rank 1



RGB 457 - Rank 4



RGB 467 - Rank 17

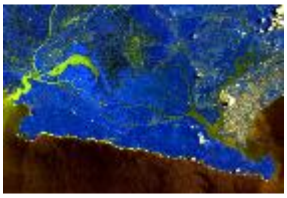


RGB 567 - Rank 6

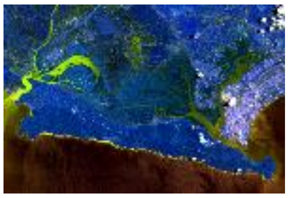
Attachment 2: RGB Composites of Sentinel 2A Imagery

RGB 234 - Rank 20

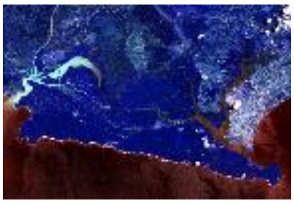
RGB 235 - Rank 18



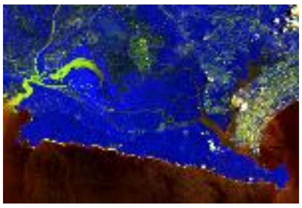
RGB 238a - Rank 9



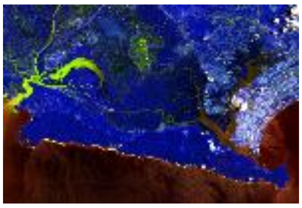
RGB 2311 - Rank 16



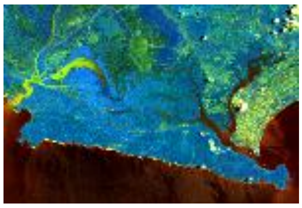
RGB 245 - Rank 19



RGB 248a - Rank 5

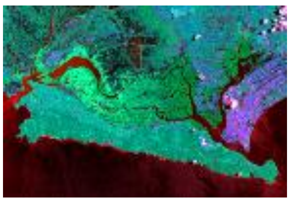


RGB 2411 - Rank 13



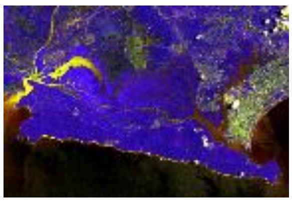
RGB 258a - Rank 8

RGB 2511 - Rank 12

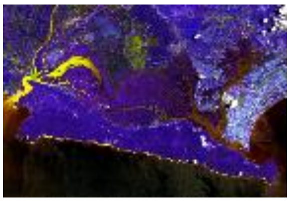


RGB 28a11 - Rank 4

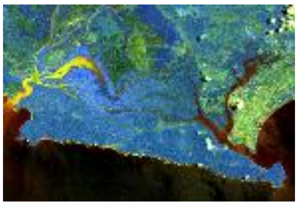
RGB 345 - Rank 17



RGB 348a - Rank 3

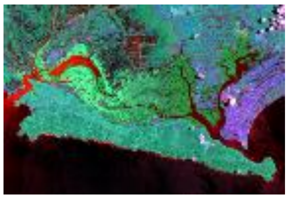


RGB 3411 - Rank 11

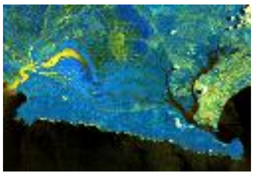


RGB 358a - Rank 10

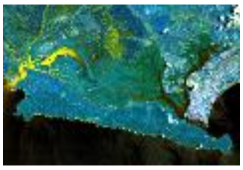
RGB 3511 - Rank 14



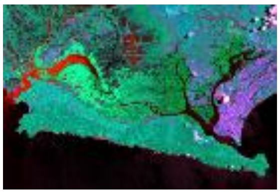
RGB 38a11 - Rank 7



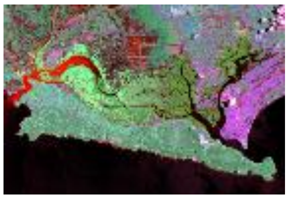
RGB 458a - Rank 2



RGB 4511 - Rank 15



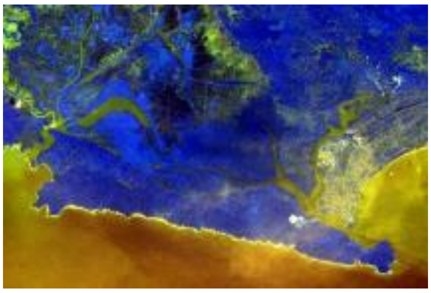
RGB 48a11 - Rank 1



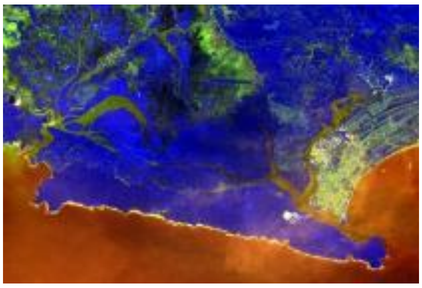
RGB 58a11 - Rank 6

Attachment 3: RGB Composites of SPOT 6 Imagery

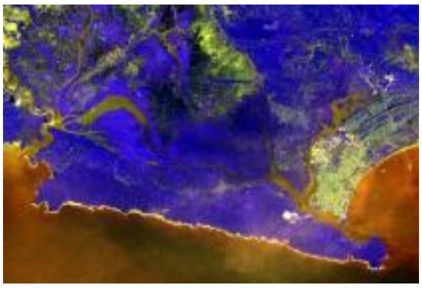
RGB 123 - Rank 4



RGB 124 - Rank 3



RGB 134 - Rank 1



RGB 234 - Rank 2