MONITORING OF MANGROVE GROWTH AND COASTAL CHANGES ON THE NORTH COAST OF BREBES, CENTRAL JAVA, USING LANDSAT DATA

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Abstract. Severe abrasion occurred in the coastal area of Brebes Regency, Central Java between 1985 and 1995. Since 1997, mangroves have been planted around the location as a measure intended to prevent further abrasion. Between 1996 and 2018, monitoring has been carried out to assess coastal change in the area and the growth and development of the mangroves. This study aims to monitor mangrove growth and its impact on coastal area changes on the north coast of Brebes, Central Java Province using Landsat series data, which has previously proven suitable for wetland studies including mangrove growth and change. Monitoring of mangrove growth was analysed using the normalised difference vegetation index (NDVI) and the green normalised difference vegetation index (GNDVI) of the Landsat data, while the coastal change was analysed based on the overlaying of shoreline maps. Visual field observations of WorldView 2 images were conducted to validate the NDVI and GNDVI results. It was identified from these data that the mangroves had developed well during the monitoring period. The NDVI results showed that the total mangrove area increased between 1996 and 2018 about 9.82 km^2, while the GNDVI showed an increase of 3.20 km^2. Analysis of coastal changes showed that the accretion area about 9.17 km^2 from 1996 to 2018, while the abrasion being dominant to the west of the Pemali River delta about 4.81 km^2. It is expected that the results of this study could be used by government and local communities in taking further preventative actions and for sustainable development planning for coastal areas.

Keywords: *abrasion, accretion, NDVI, GNDVI*

1 INTRODUCTION

Coastal areas represent a transitional zone between land and sea in which each influences the other, making coastal areas very important both ecologically and economically. Ecosystems in such areas develop with diverse species and densities, including mangroves, coral reefs, estuaries and deltas. Even large cities and urban agglomerations are abundant in coastal areas (Von Glasow et al., 2013). Therefore, natural resources in coastal areas have great potential to be sources of income for communities and countries, from such activities such as fisheries, tourism and ports and from resources such as sand and minerals. It is important therefore for coastal areas to be protected and preserved to maintain future sustainability, particularly since pressure on such areas continues to increase year on year.

Coastal areas are at risk of abrasion by waves, currents and other phenomena, causing some coastal areas to decrease in size or disappear entirely (Susandi, Firdaus, & Herlianti, 2008).

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Rising sea levels due to climate change are also exacerbating abrasion in coastal areas. Such abrasion has occurred in various regions in the world, including Indonesia. Luk'yanova, Saf'yanov, and Solov'eva (2002) found that in Russia erosion had occurred on more than 25,000 km of coastlines, that up to 5000 ha of coastal area had vanished every year, and that up to 115 million tonnes of sediment per year had been deposited in the sea. In Lithuania, Dubra (2006) identified that about 92 km of beach had been eroded by the Baltic Sea. The main area of abrasion of up to seven metres a year noted by these researchers took place near Palanga in Western Lithuania, where breakwaters that had previously stabilised the coast were destroyed. Barbaro (2013) identified that the Calabrian coast in Southern Italy was affected by erosion over more than 700 km of coastline. Othman (1994) mentioned that almost 30 per cent of coastlines in Malaysia had also been eroded.

In Indonesia, abrasion occurs in most coastal areas, including in the outer islands. Geurhaneu and Susantoro (2016) found that abrasion occurred on Putri Island, Batam, and Riau Islands Province between 2000 and 2016, causing a decrease in land area of up to 107,108 m^2. Andreas et al. (2018) found that abrasion had occurred very quickly along the northern coast of Java. Likewise, tidal inundation, which had previously been of only a few centimetres, could now be more than half a metre into the mainland. Wisnu et al. (2016) suggest that abrasion-prone locations exist on the northern coast of Central Java Province, including Brebes, Demak, Rembang, Jepara, Kendal, Tegal, Semarang and several parts of Pekalongan District. Damage to mangrove forests in these locations is one of the causes of high abrasion vulnerability. Jonata (2016) explains that abrasion in Brebes District had occurred since 1985, the most severe example in 1995 having damaged 1,100 ha of ponds. Mangrove areas also decreased by about 68.46 ha a year (Faperi, Hendrarto, & Radjasa, 2015).

Ecologically, coastal ecosystems are important for human life, and so conservation, protection, and community involvement are needed to maintain their sustainability. Thus, coastal protection is an important issue that must be addressed to prevent serious coastal erosion. Likewise, the decline in mangrove forests over the past few decades in Indonesia must be prevented. One of the efforts undertaken to prevent abrasion in coastal areas is the planting of mangroves, and this activity has been ongoing in Brebes District since 1997 (Tariah, 2016) and intensively since 2005 (Jonata, 2016). Ecosystem rehabilitation of this type needs to consider the following aspects: prioritisation of ecological rehabilitation, effective rehabilitation, accompaniment with sustainability, consideration of whether physical rehabilitation should be implemented, and ways of harmoniously living with the ecosystem (Cerlyawati, Anggoro, & Zainuri, 2017).

Monitoring was implemented to investigate mangrove growth and coastal changes from 1996 to 2018. This study was conducted using remote sensing technology that has been proven to be beneficial in delineating mangrove and non-mangrove areas both spatially and temporally. The remote sensing data employed were Landsat series, as these have been proven to be suitable for wetland research (Guo, Li, Sheng, Xu, & Wu, 2017), supported by WorldView-2 and field observations. This study aimed to monitor the growth of mangroves and the impact of such development on coastal changes in Brebes District, Central Java Province, and its surroundings, based on the available remote sensing data and a simple processing approach. It is hoped that this study will provide information about mangrove growth and the abrasion that is still taking place in these areas so that effective measures can be taken.

Remote sensing has developed to meet the need for low-cost management information for large areas in terms of global coverage and repetitive measurement capability (Tueller, 1987; Verstraete and Pinty, 1991). The Landsat series are used because the Landsat sensor is adapt perfectly for ecological monitoring of large areas; has the ability to allow long-term change detection; and includes data acquisition, processing, archiving, distribution and pricing policies that facilitate widespread use of the data produced (Wulder et al., 2008). However, problems of cloud and cloud shadow can affect the accuracy of vegetation analysis in Landsat series data (Wang, Franklin, Guo, Mcdermid, & Tn, 2009).

2 MATERIALS AND METHODOLOGY

2.1 Study area

The research area covers Kaliwlingi and West Randusanga villages (Brebes Sub-district) and Sawojajar village (Wanasari Sub-district) of Brebes District, Central Java Province, Indonesia. This area is located in the Pemali River delta in the western part of Central Java Province, about 175 km from Semarang City and about 250 km from Jakarta (Figure 2-1). Geologically, the surface sediments consist of coastal and alluvium deposits. The coastal deposits consist of mud, which is found in swampy areas, and mud and grey clay containing skins of molluscs along the coast, the thickness of which reaches several metres. The alluvium deposits consist of gravel, sand and grey clay along river floodplains and with thickness of around five metres (Djuri, Samodra, Amin, & Gafoer, 1996; Silitonga, Masria, & Suwarna, 1996). The research area is surrounded by ponds and mangrove areas, and several rivers flow into it. The area of fish ponds in Sawojajar village is 1,579.10 ha, in Kaliwlingi village is 734.53 ha, and in Randusanga Kulon village is 1,161.50 ha. Mangroves grow on the Pemali River delta, along the coast and between fish ponds (Central Bureau of Statistics, 2017).

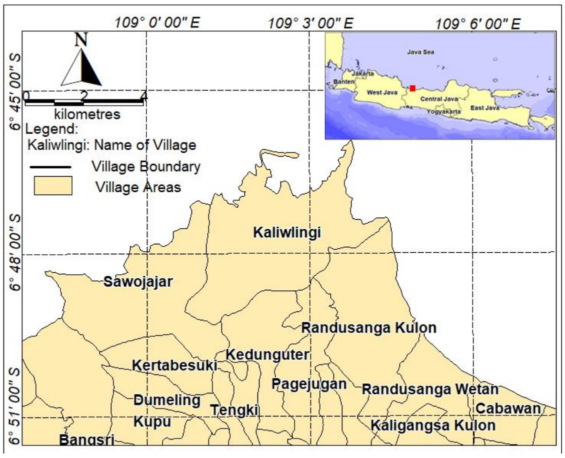

Figure 2-1: Study area located on the north coast of Brebes, Central Java Province

2.2 Remote sensing data used

The data employed for this study were drawn from Landsat-5 TM, Landsat-8 OLI and WorldView-2 (Table 2-1). Landsat-5 TM was launched on March 1, 1984, by NASA and produces six band images with 30-metre resolution for bands 1–5 and 7, and a thermal band (band 6). Landsat-5 TM ceased operating in November 2011 (Earth Observing System, 2018). Landsat-8 OLI was launched on February 11, 2013, and is a continuation of Landsat-7 ETM+ and Landsat-5 TM with slight differences in spectral response (Flood, 2014). Landsat-8 OLI produces seven band images with 30-metre spatial resolution visible to short-wave infrared (SWIR) (OLI) and 100-

metre spatial resolution of thermal infrared sensors (TIRS) (Irons, Dwyer, & Barsi, 2012). For this study, LANDSAT-5 TM and Landsat-8 OLI data were downloaded from the EarthExplorer data portal (https://earthexplorer.usgs.gov/).

Launched in October 2009, WorldView-2 provides high-resolution images with eight multispectral bands and one panchromatic band. The multispectral band resolution is 1.85 metres, while the panchromatic band is 46 cm. The multispectral bands consist of four colours: blue, green, red and near IR 1; and four new colours: coastal, yellow, red edge and near-IR2 (DigitalGlobe, 2018).

Table 2-1: Remote sensing data used

No.	Remote sensing data	Date recording	Sources
1	Landsat-5 TM: path/row 121/065	25/12/96 11/06/00 02/08/07 09/07/10	https://earthexplorer.usgs.gov/
2	Landsat-8 OLI: path/row 121/065	25/09/15 12/ 05/18	https://earthexplorer.usgs.gov/
3	WorldView-2	29/04/17 03/10/17	digitalglobe.com

2.3 Remote sensing data processing and analysis

Landsat imagery was processed in stages: digital number conversion from each image into radiance at top of atmosphere (ToA); conversion of ToA into earth-surface reflectance using the fast line-of-sight atmospheric analysis of spectral hypercubes (FLAASH) method. FLAASH is an atmospheric correction method based on MODTRAN4. It can generate accurate surface reflectance data in low to moderate vapour conditions, clear to moderate haze/aerosol, and nadir viewing from any altitude between the ground and ToA (Mathew et al., 2003). We also geocoded the images in the south projection zone of the 49 Universal Transverse Mercator (UTM) systems and the WGS84 of datum. To analyse the mangroves, two different spectral vegetation indices were employed: NDVI (Rouse, Haas, Schell, & Deering, 1974), and GNDVI (Gitelson, Kaufman, & Merzlyak, 1996). These indices use the NIR band but the latter band is a different, namely a visible band. The NDVI employs a red band and the GNDVI a green band (Table 2-2). The WorldView 2 images were processed to create composite images of 532 RGB, then image fusion was conducted with the panchromatic band using the Gram-Schmidt spectral sharpening method. The WorldView 2 image function was used for validation of the Landsat vegetation indices .

Table 2-2: Indices used in the monitoring of mangrove growth

Name	Algorithm	Reference
NDVI	NDVI = (NIR – red)/(NIR + red)	(Rouse et al., 1974)
GNDVI	GNDVI = (NIR-green)/NIR + green)	(Gitelson et al., 1996)

Based on the research objectives, the research location was classified as mangrove and non-mangrove areas. Then the mangrove areas were classified into several classes ranging from loose mangroves to dense mangroves, and the results were employed to monitor their growth. We also analysed coastline changes by overlaying the coastline maps for 1996, 2000, 2005, 2010, 2015 and 2018. The coastline was interpreted visually on the Landsat 8 OLI 653 RGB, Landsat TM-5 542 RGB. In this case, we did not use the normalised difference water index (NDWI), because it had problems in interpreting coastline on coasts with muddy substrates (Winarso, Judijanto, & Budhiman, 2001). Coastline changes were expressed in the form of abrasion and accretion areas over a period of time. In this research we did not consider the effect of tides on coastline change. We assumed that tide is not a significant impact in coastline change.

Field observation for validation was carried out on the western part of the Pemali River delta at the end of December 2017. The classification results of Landsat series were identified as ponds, mangroves with loose to dense cover, and abrasion and accretion areas. The overall validations were performed using WorldView 2 high-resolution images and field observations. A correlation analysis was also conducted for mangrove area expansions resulting from the NDVI and the GNDVI with accretion and abrasion areas, using linear regression to produce mathematical equations and coefficients of determination (R^2). The detailed flow diagram for this research can be seen in Figure 2-2**.**

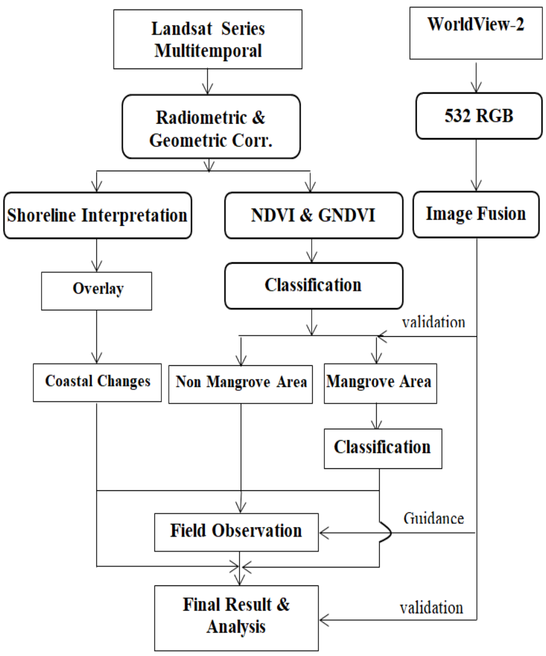

Figure 2-2: Flow diagram of the research

The reasons we used NDVI and GNDVI include: (1) NDVI for mangrove mapping displays a positive correlation with mangrove distribution and its results can represent mangrove growth (Xiao, Su, Fu, Wang, & Huang, 2020); (2) NDVI can be used to enhance the accuracy of land-use mapping and also shows land-cover changes due to human activities (Thakur, Kumar, & Palria, 2019); (3) the use of NDVI and soil adjusted vegetation index (SAVI) can also clearly distinguish between vegetation and non-vegetation classes compared to the supervised classification method (Rhyma, Norizah, Hamdan, Faridah-Hanum, & Zulfa, 2020); (4) GNDVI is more sensitive than NDVI to chlorophyll (Chl_{ab}) content at levels of 0–65 $\mu g cm^{-2}$, because NDVI employs a red band while GNDVI employs a green band (Eitel et al., 2011).

3 RESULTS AND DISCUSSION

3.1 Mangrove growth

The NDVI and the GNDVI values in mangrove areas were classified into six classes: fish pond/water body, barren land, very sparse mangroves, sparse mangroves, rather dense mangroves, and dense mangroves (Figure 3-1 and Figure 2-2). The results indicate that the mangrove conditions in Brebes District changed extensively between 1996 and 2018, with NDVI results showing that mangrove areas increased from 7.16 km^2 in 1996 to 16.96 km^2 in 2018 (Figure 3-3). Based on the NDVI, the average mangrove area expansion was about 1.96 km^2 per year, with the increase mainly occurring in Kaliwlingi and Randusanga Barat villages, located in the Pemali River delta. However, mangrove cover in these locations is still dominated by very sparse mangroves, at an average density of 58 per cent, followed by sparse mangrove, rather dense mangrove and dense mangrove with averages of 24 per cent, 10 per cent and 8 per cent, respectively. This situation occurs because mangroves predominantly grow around ponds and along the coast. These results are consistent with previous research which found that mangroves in Brebes District were dominated by very sparse growth, based on direct observation in the field in May to July 2013 (Suyono, Supriharyono, Hendrarto, & Radjasa, 2015).

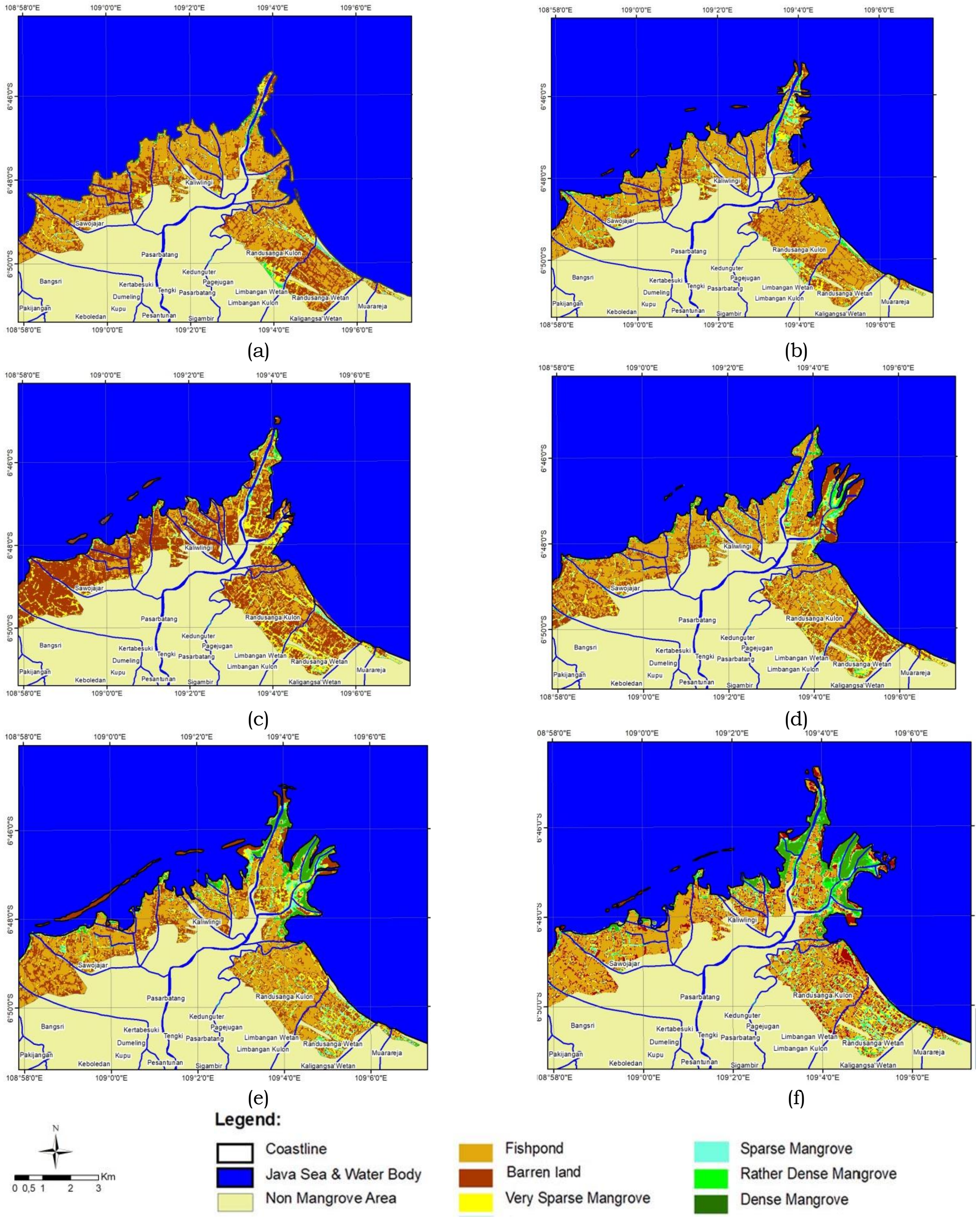

Figure 3-1: Mangrove maps based on NDVI for Brebes District: a) 25 December 1996, b) 11 June 2000, c) 2 August 2007, d) 9 July 2010, e) 25 September 2015, and f) 12 May 2018

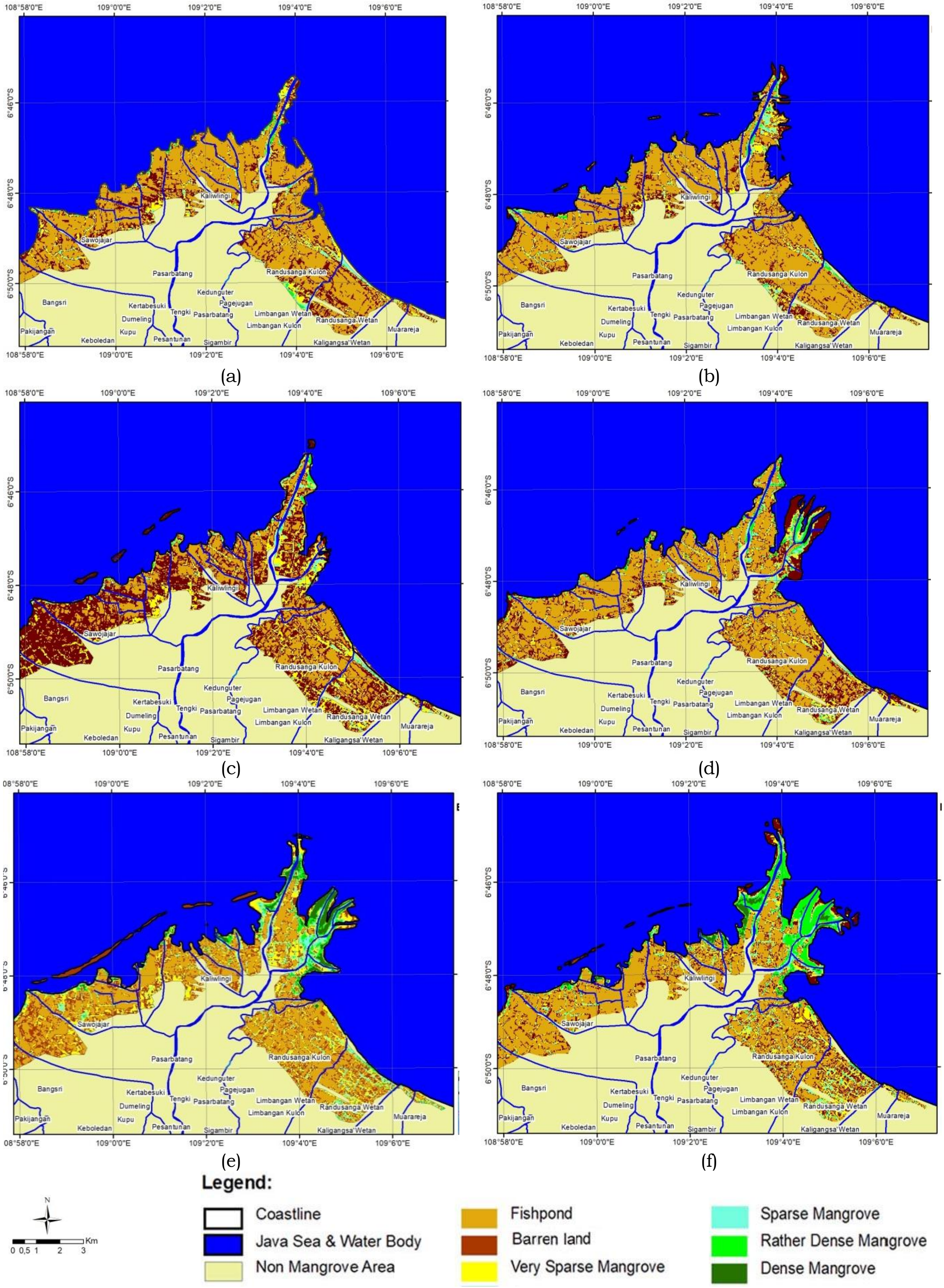

Figure 2-2: Mangrove maps based on GNDVI for Brebes District: a) 25 December 1996, b) 11 June 2000, c) 2 August 2007, d) 9 July 2010, e) 25 September 2015, and f) 12 May 2018

The NDVI analysis for the year 1996, which was one year after a period of severe abrasion, showed that mangrove condition was poor. Fairly dense mangroves comprised about 7 per cent of the mangrove area, and dense mangrove only about 1 per cent. In 1997, a group of natural resources conservationists initiated the planting of mangroves around ponds and river banks (Tariah, 2016). This planting was successful, with NDVI analysis indicating that mangrove areas with very sparse and sparse density had increased by the year 2000. NDVI analysis in 2007 showed that mangrove areas with sparse density continued to increase, and this was in parallel with previous studies stating that mangroves had been very intensively planted since 2005 (Jonata, 2016). Mangrove cover began growing well in the period 2010 to 2018. Rather dense to dense cover was 1.54 km^2 in the year 2010, increased to 3.20 km^2 in 2015 and to 5.75 km^2 in 2018 (Figure 3-4).

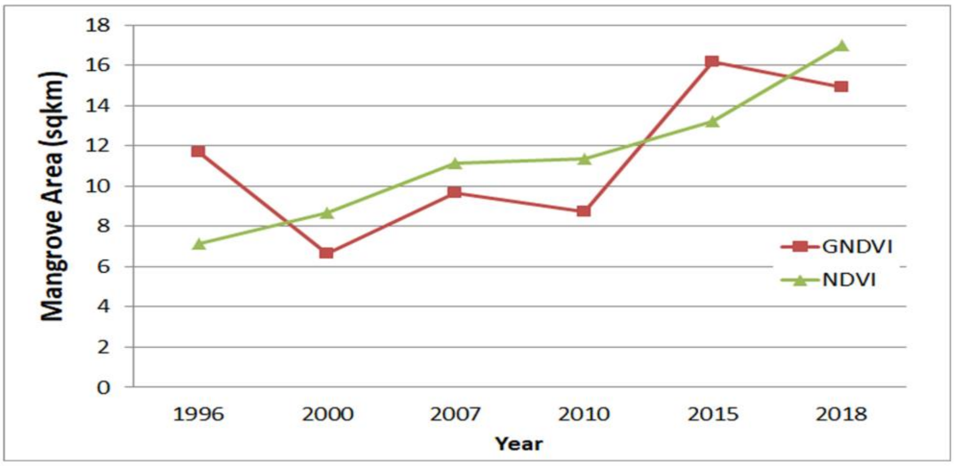

Figure 3-3: Graphs of mangrove area changes in the Brebes District from 1996 to 2018

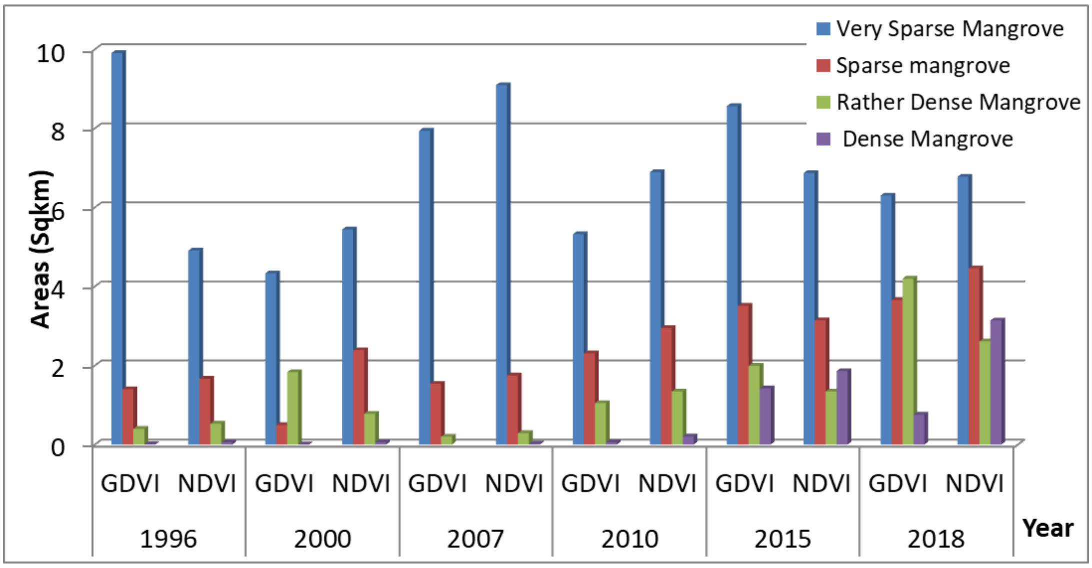

Figure 3-4: Mangrove areas based on NDVI and GNDVI in Brebes Regency.

The GNDVI algorithm showed a difference from the NDVI algorithm. Based on the GNDVI, mangrove areas in the year 1996 were 11.71 km^2 and in the year 2018 were 14.90 km^2 (increase of 3.20 $km^{2)}$ (Figure 2-2 and 3-4). The average addition of mangrove area based on the GNDVI analysis was about 0.64 km^2 per year. In detail, the GNDVI analysis showed that the mangrove area decreased by 5.05 km^2 between 1996 and 2000, and then from 2000 to 2007 increased by 3.01 km^2 to 9.67 km^2. Mangrove area then declined in 2010 by 0.94 km^2 to 8.73 km^2 and then increased in 2015 to 16.18 km^2; then in 2018, it declined again to 14.90 km^2. However, in general, the results of the NDVI and the GNDVI analyses show that the mangrove planting in Brebes District and the surrounding areas has been successful, as shown by the overall increase in mangrove area from 1996 to 2018.

Field observations showed that mangroves had been intensively planted by communities, government and related institutions in more than 36 locations between 2005 and 2017. Based on the planting data, it is estimated more than 3,000,000 mangrove trees were planted. In 2005, self-financed communities and forestry and plantation offices planted approximately 40,000 trees around ponds and along the coast, followed by around 35,000 trees in 2006. Starting in 2008, mangrove planting was funded by various agencies, such as the government, companies and NGOs. This collaboration was put in place to improve the successful restoration of mangroves in these areas.

3.2 Shoreline changes

The coastline changes in Brebes District were the result of abrasion and accretion. The abrasion was caused by sea waves and currents that eroded land along the coastal area, with rising sea levels also acting as a controller for abrasion in coastal areas (Luk'yanova et al., 2002). Accretion takes place because particles carried by rivers are deposited forming deltas or sandbars. Therefore, accretion tends to occur at the mouths of rivers and has an effective role in slowing down water flow, so that it efficiently traps sediments from suspended particles and affects land accretion as well as providing a buffer from potential sea-level rise in the future (Walters et al., 2008).

Abrasion and accretion in Brebes District between 1996 and 2018 can be seen in Figure 3-5 and Table 3-1. From 1996 to 2000, abrasion was dominant in the western and eastern parts of the study area, mostly affecting ponds, which are estimated to have reduced by around 2.19 km^2. Accretion was dominant in the Pemali River estuary. From 2000 to 2007 the location of abrasion moved to the east of the Pemali River delta. This was influenced by changes in the Pemali River's branching which caused sedimentations on the east to increase. Total accretion was around 3.12 km^2, while abrasion was around 1.65 km^2. From 2007 to 2010, abrasion was dominant to the west of the study area, while accretion increased in the eastern part of the delta, as a continuation from the period 2000 to 2007. From 2010 to 2015, accretion was dominant around the mouth of the Pemali River and abrasion was dominant to the west of the study area, causing sediment to be carried away and deposited in the sea at a distance of 1–2 km, forming a sandbar. From 2015 to 2018 abrasion decreased but was still located in the west of the study area.

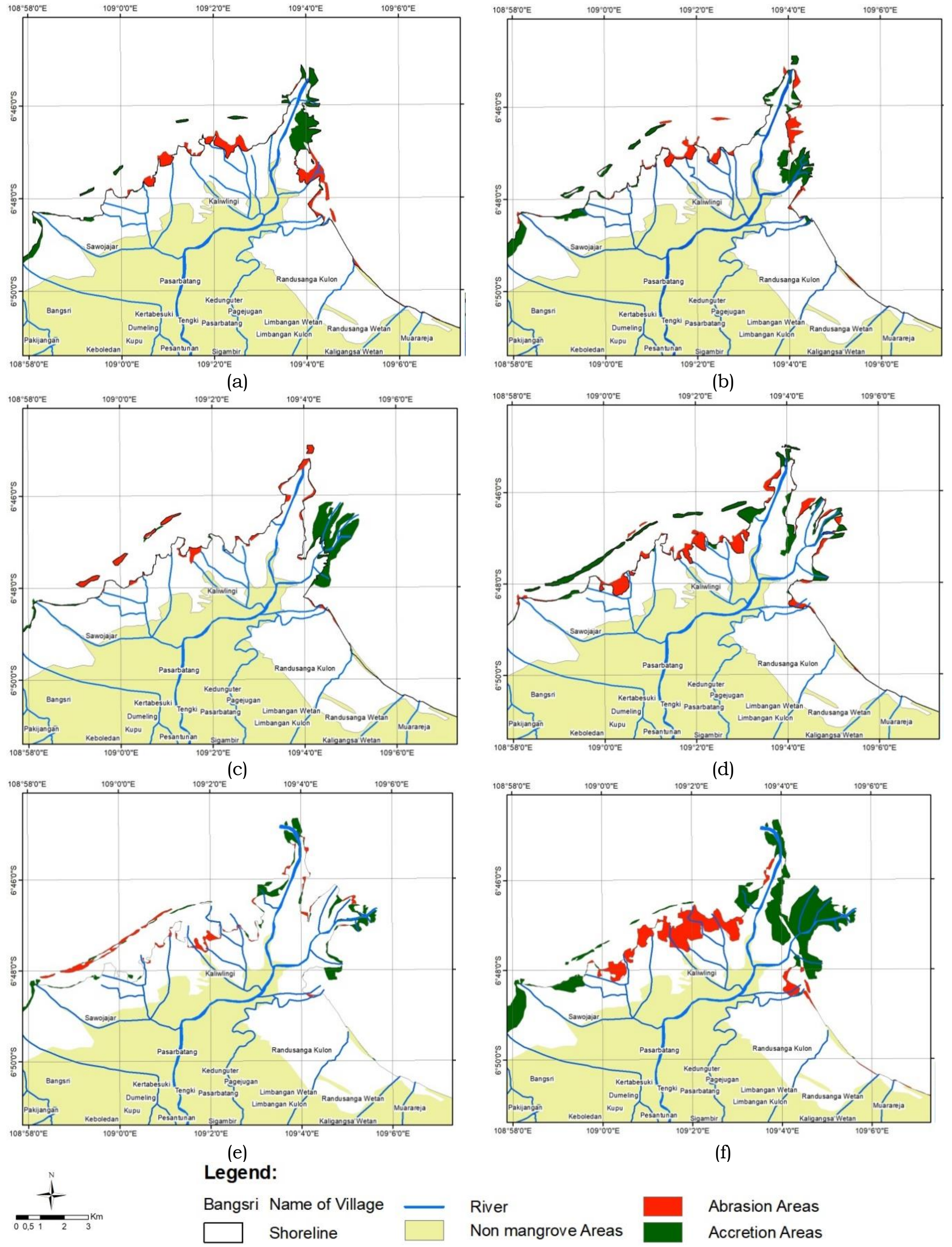

Figure 3-5: Shoreline change maps representing accretion and abrasion during 1996–2018: a) 1996 to 2000, b) 2000 to 2007, c) 2007 to 2010, d) 2010 to 2015, e) 2015 to 2018, and f) 1996 to 2018.

Table 3-1: Coastal changes in Brebes District 1996 to 2018.

Status	Coastal changes by year (km^2)					
	1996 to 2000	2000 to 2007	2007 to 2010	2010 to 2015	2015 to 2018	1996 to 2018
Accretion	2.35	3.12	3.05	3.01	2.41	9.17
Abrasion	2.19	1.65	1.33	2.84	1.27	4.81

In general, the area of accretion was wider than the area of abrasion. Accretion was dominant to the east of the study area, while abrasion was dominant to the west. From 1996 to 2018 the total accretion area was around 9.17 km^2 while the abrasion area was around 4.81 km^2 (Table 3-1). Accretion was influenced by the amount of sediment deposited around the coastal area being greater than the amount of sediment transported to the sea (Suyono et al., 2015). Sedimentary deposits that caused this accretion were influenced by high sediment transport by the Pemali River. This is common in river estuaries and has been described in a previous study conducted by Anggraini, Marpaung, & Hartuti (2017). However, the abrasion around the study area triggered the formation of a sandbar at a distance of 1–2 km from the coastline. The first time the sandbar was identified in the Landsat imagery was in 2000, located in the northwest of the study area. The sandbar was in part forming as a permanent island, but the other part was dynamic and changing, both as an increasing and decreasing area. The greatest sandbar formation took place in 2015, with a length of more than 5 km.

3.3 Analysis of the differences in NDVI and GNDVI results

The results obtained from the NDVI and the GNDVI for mangrove growth in the study area differed. Field observations at several locations were conducted to evaluate these contrasting results. A comprehensive observation was also conducted of WorldView 2 images to identify whether the results of the analyses of vegetation indices were consistent. Based on the observations, the NDVI provided better classification than the GNDVI. The NDVI results were compatible with the mangrove conditions found in the WorldView 2 images and with visual observations in the field (Figure 3-6). The results of this study are consistent with the research conducted by Haboudane, Miller, Pattey, Zarco-Tejada, and Strachan (2004), finding that the NDVI is suitable for vegetation cover fraction estimation. The GNDVI has a density saturation problem in relation to canopy cover. Barati, Rayegani, Saati, Sharifi, and Nasri (2011) explain that in a loosely vegetated area, the GNDVI is a less sensitive vegetation index for vegetation cover fraction variations. In addition, with increasing age the chlorophyll content in mangrove leaves in certain phase changes. Based on the results of the GNDVI, it is estimated that if the chlorophyll content is reduced the index values decrease. This is consistent with studies by Gitelson et al. (1996) and Eitel et al. (2011) which explain that the GNDVI is more sensitive to chlorophyll content variations than the NDVI.

Linear regression analysis also showed that the mangrove area expansion obtained from the NDVI analysis correlated with both accretion and abrasion. Simple linear regression analysis showed that the mangrove area expansion from the NDVI analysis had a good correlation with accretion and abrasion, while mangrove area expansion from the GNDVI analysis had low correlation with abrasion and accretion. The correlation between mangrove area expansion from the NDVI analysis and accretion had a coefficient of determination (R^2) of 0.577 and abrasion had R^2 of 0.1617; and both accretion and abrasion had R^2 of 0.8868 (Figure 3-3-7). The correlation between mangrove area expansion from the GNDVI analysis for accretion had R^2 of 0.0768 and abrasion had R^2 of 0.1514; both accretion and abrasion had R^2 of 0.0177 (Figure 3-7).

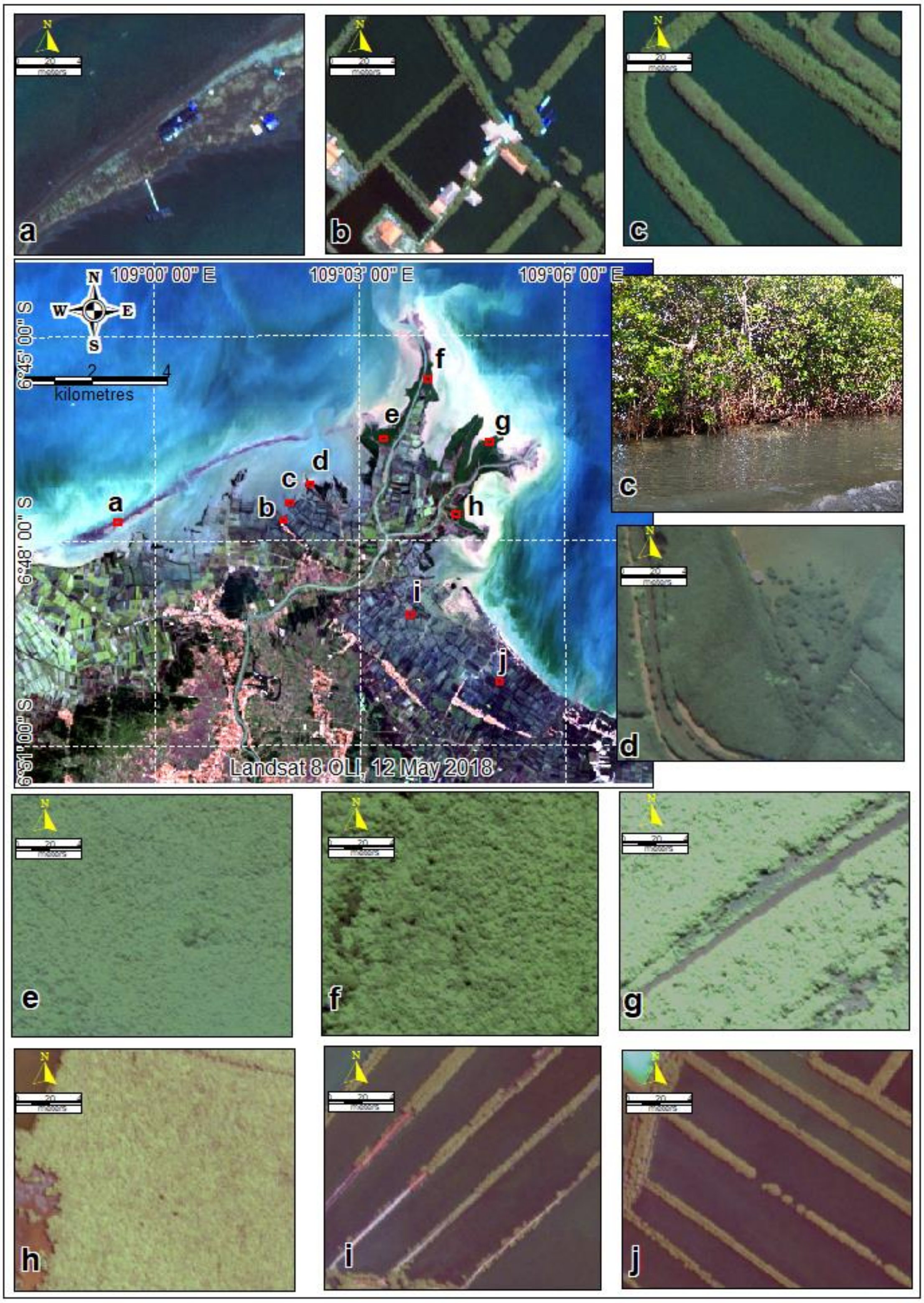

Figure 3-6: The appearance of mangrove from WorldView 2 images: a) sandbar; b) mangrove on riverbanks; c) mangrove directly facing the sea; d) dense mangrove and tourist sites; e), f), g) and h) dense mangrove; i) and j) sparse mangrove around ponds

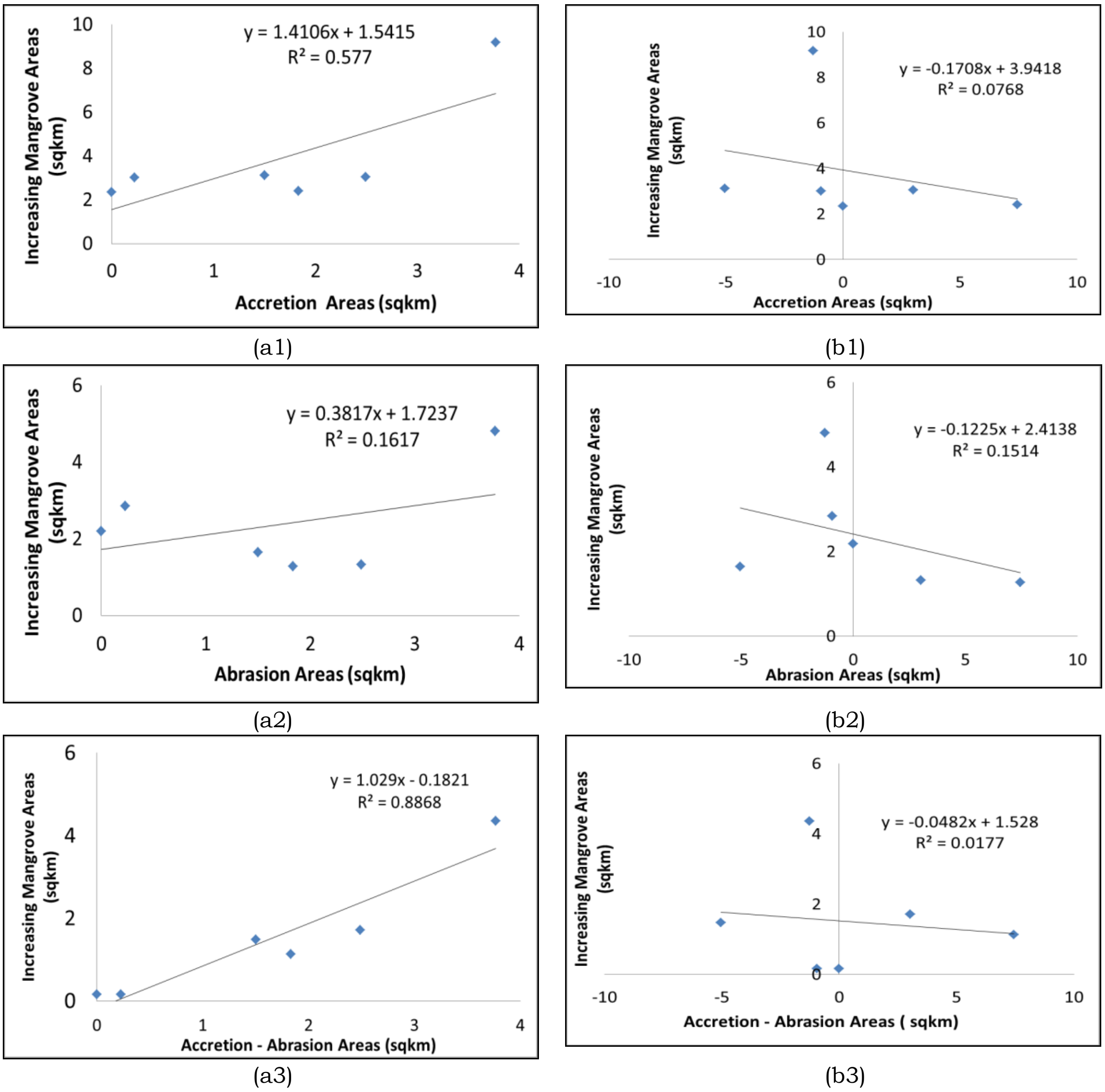

Figure 3-7: The correlation of increasing of mangrove area between vegetation indices to accretion and abrasion: a1) NDVI with accretion; a2) NDVI with abrasion; a3) NDVI with accretion and abrasion; b1) GNDVI with accretion; b2) GNDVI with abrasion; b3) GNDVI with accretion and abrasion

A multiple linear regression analysis was performed on mangrove area expansion drawn from the NDVI and the GNDVI. The results showed that the mangrove area expansion resulting from the NDVI had very good correlation with accretion and abrasion with R^2 of 0.965, formulated with the following equation: $Y = 0.926 + 1.083A - 1.473B$, where Y is the mangrove area expansion from the NDVI, A is accretion and B is abrasion. A multiple linear regression between the mangrove area expansion from the GNDVI and both accretion and abrasion had low correlation, with R^2 of 0.177, formulated with the following equation: $Y = 3.586 + 0.581A - 2.253B$, where Y is mangrove area expansion from the GNDVI, A is accretion and B is abrasion. There is a good correlation between mangrove area expansion and both abrasion and accretion because the land resulting from accretion is the main target of mangrove planting in the study area. The mangrove planting model is carried out directly with propagules, enabling it to be efficient and highly environmentally adaptable. The roots that grow from the propagules are strong and penetrate directly into their habitat

(Tariah, 2016). This type of planting aims to protect the land from potential abrasion in the future.

4 CONCLUSION

Pursuant to the analysis of vegetation indices, the mangrove planting programme in Brebes District showed a high success rate, in which mangrove area increased between 1996 and 2018. Mangrove growth monitoring using the NDVI and the GNDVI gave different results for the development of mangrove areas. The results of analysis based on visual observations of WorldView 2 high-resolution images and field survey results and correlation between vegetation indices and both accretion and abrasion showed that the NDVI was better than the GNDVI in delivering accurate results. Mangrove area expansion based on the NDVI was in line with the development of the delta in the study area. Accretion in the study area from 1996 to 2018 was estimated at 9.17 km^2, while abrasion was around 4.81 km^2. Accretion was higher than abrasion because mangroves could trap sediments and accumulated sediment transported by rivers which was then deposited at the river mouth. However, the abrasion took place continuously and dominantly to the west of the river mouth.

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AUTHOR CONTRIBUTIONS

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