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Coastal dynamic and shoreline mapping: multi-sources spatial data analysis in Semarang Indonesia

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Abstract Semarang coastal area has geomorphologically complex processes, such as erosion-sedimentation, land subsidence, and tidal inundation hazard. Multi-years shoreline mapping is considered a valuable task for coastal monitoring and assessment. This paper presents maps illustrating the shoreline dynamic in a coastal area of Semarang-Indonesia using multi-sources spatial data. The segment data has been obtained by visual delineation of the topographic maps Year 1908, 1937, 1992 and Ikonos image Year 2003 as well as digital number (DN) value analysis and masking operation of Landsat MSS Year 1972 and Landsat ETM Year 2001. For the long period of almost 100 year, the shoreline dynamic in Semarang coastal area is dominated by sedimentation process. Shoreline extended to the sea as a result of man-made infrastructure and natural processes. The research's result was satisfactory and the method has proven to be effective considering lack of homogeneous data-series. However, some further improvement regarding geo-processing can be made and the accuracy can be tested in future version.

Keywords Shoreline dynamic · Multi-sources spatial data · Visual interpretation · Digital number value analysis · Semarang-Indonesia

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Introduction

The coastal area consists of the interface between land and sea. It is a highly dynamic environment with many physical processes, such as tidal inundation, sea level rise, land subsidence, and erosion-sedimentation. Those processes play an important role for the shoreline change and coastal landscape development. In addition, urban development on the coastal area and resource use conflicts spawn environmental degradation and increasing hazard vulnerability (Dey et al. 2002; Mills et al. 2005). According to Bird and Ongkosongo (1980) the building of sea walls and breakwaters, the advancement of the shoreline artificially by land reclamation, and the removal of beach material from the coastline brought effects directly on the coastal change. The changes in water and sediment yield from river systems following the modification of land use within the catchments brought indirect impacts to the coastal changes.

Shoreline change is considered one of the most dynamic processes in coastal area (Bagli and Soille 2003; Sunarto 2004; Mills et al. 2005). In many coastal areas in the developing countries, dense population being placed next to the shoreline creates the more vulnerable areas. It has become important to map the shoreline change as an input data for coastal hazard assessment. There are many change detection techniques currently in use including visual interpretation, spectral-value-based technique (differencing, image regression, DN value analysis), multi-data composites, and change vector analysis.

Visual interpretation of multi-temporal images for coastal monitoring was presented by Mazian et al. (1989); and Elkoushy and Tolba (2004). Meanwhile, Mills et al. (2005) introduced the integration of the geomatics techniques to form accurate representations of the coastline. A highly accurate DEM, created using kinematics GPS, was used as control to orientate surfaces derived from the relative orientation stage of photogrammetry processing. Mostafa and Soussa (2006) have applied GIS and remote sensing technique to monitor the lake of Nasser including the shoreline dynamic. Three satellite Landsat images for Nasser Lake was available in a time series (1984, 1996, and 2001). Topography map of scale 1:50,000 that is suitable to the resolution of Landsat images, was used for developing DEM. The research reported that the satellite image in a good data-series helped in detecting the changes in the lake shape. Wang et al. (2003) investigated a novel approach for automatic extraction of shoreline from Ikonos images using a mean shift segmentation algorithm. Furthermore, Di et al. (2003) presented a similar method using semi-automatic shoreline extraction from high-resolution Ikonos satellite imagery. Bagli and Soille (2003) analyzed DN value using slicing operation for change monitoring. In addition, Whithe and El Asmar (1999) introduced an algorithm function and DN analysis to deviate the water from the land. The DN value analysis has also been applied on Landsat images, e.g. by Frazier and Page (2000); Yanli (2002), and Marfai (2003a). Meanwhile Chalabi et al. (2006) applied DN threshold on Ikonos image for shoreline monitoring.

Monitoring a process over a specific time or a long period needs a homogenous long series data such as frequent images with an optimal spatial resolution. However, in reality it is very difficult to have a good data-series with optimal resolution, especially in the developing countries such as Indonesia. Integration multi-scale data analysis may be considered to overcome the problem related data-series availability. The integration of the different spatial and temporal resolution have been conducted by various researches in various cases, such as those by Armenakis et al. (2003); Zimmermann and Bijker (2004); Shrestha (2005); Chalabi et al. (2006); Ozdarici and Turker (2006), and Xiaodong et al. (2006). Armenakis et al. (2003) introduced automation in the assessment of scanned topographic maps and landsat ETM+imagery for feature separation and extraction in Northern Canada. The analysis of two dataset, namely scanned map and Landsat 7 etm+imagery enables the detection of features to be compared at the “information level”. It means that the comparison of the features has been made after individual processing data is finished. Chalabi et al. (2006) assessed multi-data sources for monitoring shoreline in Kuala Terengganu, Malaysia using Ikonos and aerial photographs. The methodology proposed for the extraction of the shoreline is a pixel-based segmentation using DN threshold. Results of time series data were combined each other showing spatial change of shoreline. The research undertaken by Armenakis et al. (2003) and Chalabi et al. (2006) revealed the possibility and the capability of the multi-data sources for the change analysis.

Ozdarici and Turker (2006) performed a polygon-based classification on multi-scale images of Spot4 XS, Spot5 XS, Ikonos XS, Quickbird XS, and Quickbird Pansharpened (PS) covering an agricultural area located in Karacabey, Turkey. Meanwhile, Zimmermann and Bijker (2004) assessed a combination of low spatial and high spatial resolution imagery in term of accuracy and more thematic detail. Shrestha (2005) compared the data available from different satellites having different spatial resolutions for forest mapping and estimations. There were four sets of data, which have been used for the Shrestha’s study i.e. Ikonos, IRS 1D, LISS III, and Landsat ETM+. Even though the last three cases by Ozdarici and Turker (2006); Zimmermann and Bijker (2004),

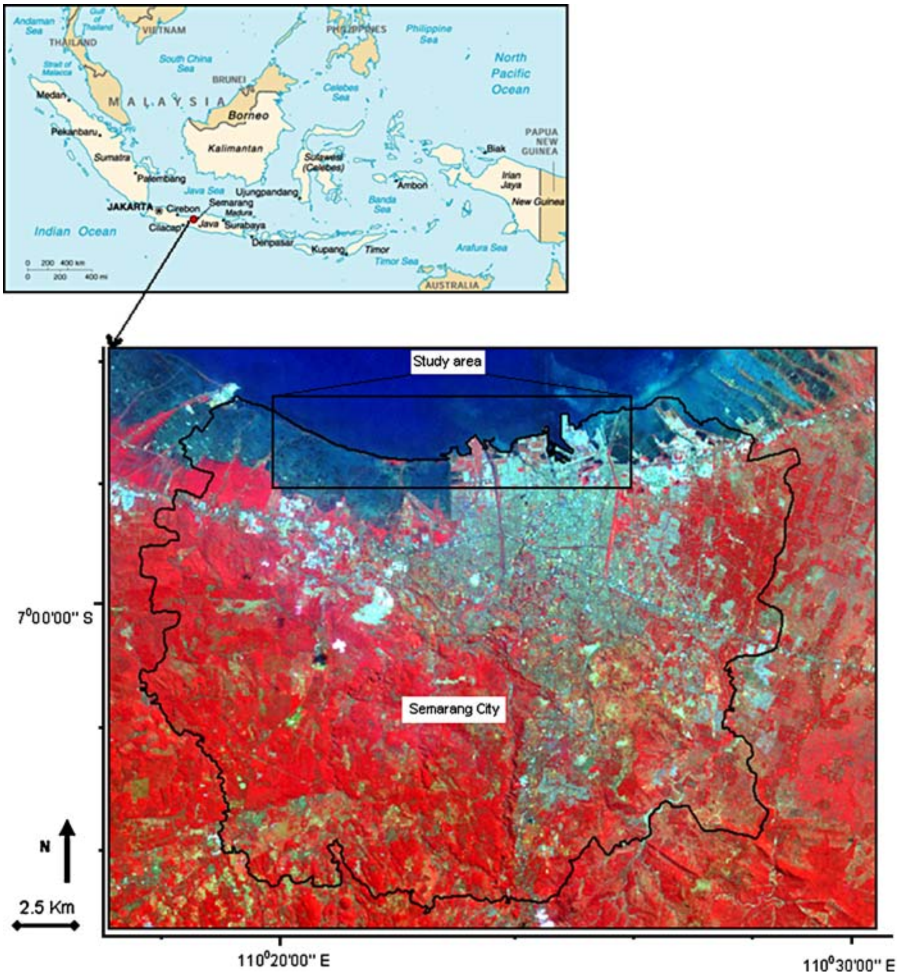


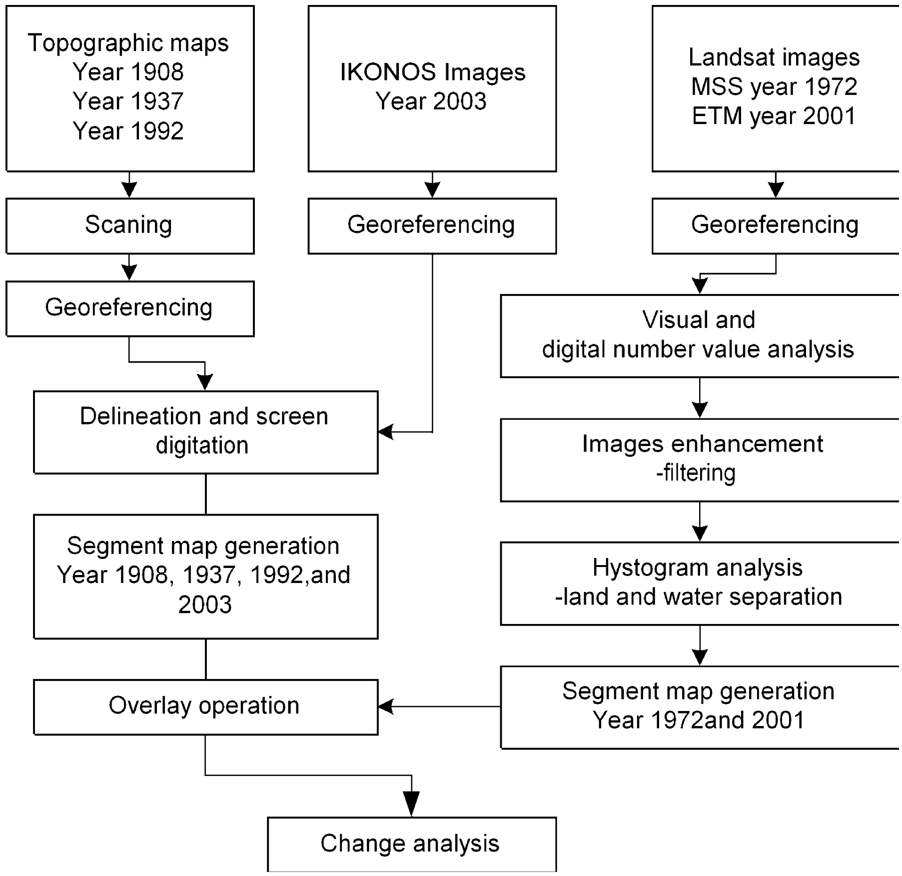
Fig. 1 The location of Semarang City

and Shrestha (2005) did not deal with the coastal monitoring, the researches have proven that the multi-scale data provide the ability for comparison mapping and detection. Furthermore, Xiaodong et al. (2006) had combined remote sensing (Quickbird) images and GIS data in change detection. The research introduced an iteratively holistic change detection using imagery and GIS data. The results of some related processes, such as features extraction of the detected objects in the remote sensing imagery and geometric co-registration

Table 1 Attributes of the dataset

Dataset	Year	Scale	Resolution	Note
Topographic map	1908	1:50,000	Scan resolution 5 m	Scanned as digital format
Topographic map	1937	1:50,000	Scan resolution 5 m	Scanned as digital format
Landsat MSS	1972	–	80 m	Band 4
Topographic map	1992	1:50,000	Scan resolution 5 m	Scanned as digital format
Landsat ETM	2001	–	30 meter	Band 5
Ikonos	2003	–	1 meter	Panchromatic

Fig. 2 Flowchart of methodology



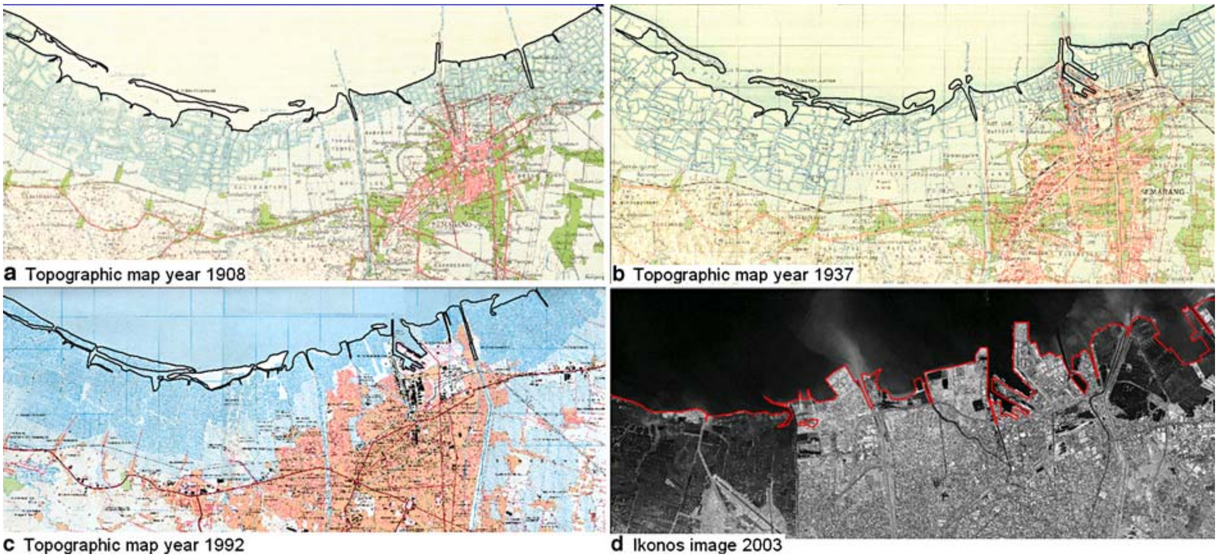


Fig. 3 Shoreline in year 1908, 1937, 1992, and 2003 from Topographic maps and Ikonos image

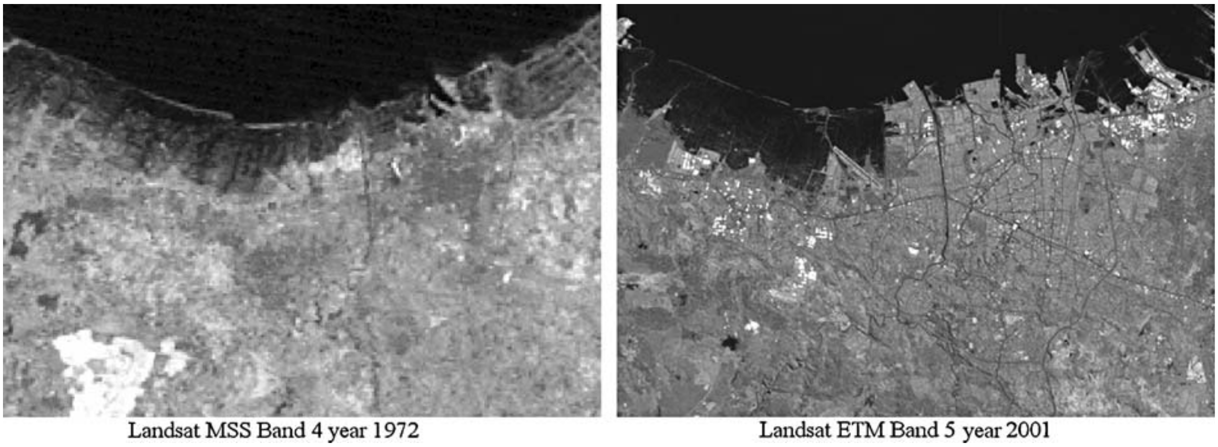


Fig. 4 Landsat MSS band 4 year 1972 and Landsat ETM band 5 year 2001

between GIS data and remote sensing imagery, have obvious influences on the results of change detection.

The present research aims to analysis shoreline change and coastal dynamic in Semarang, Central Java, Indonesia. Due to lack of the homogeneous data-series, the method using fine-resolution dataset as applied by Di et al. (2003); Wang et al. (2003), and Mills et al. (2005), could not be implemented in the research. Integrated multi-resource dataset was considered the appropriate method for the shoreline analysis in Semarang coastal area. The dataset for Semarang were Topography maps, Ikonos, and Landsat images. It was noted by Armenakis et al. (2003); Zimmermann and Bijker (2004); Shrestha (2005); Chalabi et al. (2006); Ozdarici and Turker (2006), and Xiaodong et al. (2006) that multi-scale data can be used for change analysis and mapping. The present research applied post-classification comparison method using information level domain, where the input data have been independently interpreted and then the results are compared. According to Armenakis et al. (2003) when comparing heterogeneous dataset, the change detection is performed after the data are individually processed (post-classification comparison). Visual interpretation method as also used by Mazian et al. (1989) and Elkoushy and Tolba (2004) was applied for topographic maps and Ikonos data. Meanwhile, pixel-based segmentation using DN threshold, as also mentioned by Whithe and El Asmar (1999); Frazier and Page (2000); Yanli (2002); Bagli and Soile (2003); Marfai (2003a), and Chalabi et al. (2006), was employed on the Landsat ETM and MSS data.

Study area

Semarang is a coastal urban area situated on Java Island Indonesia. Geographically, it lies between two major cities Jakarta and Surabaya. It is located at the Northern coast of Java and about 500 km East of Jakarta. Semarang is positioned at the coordinate of about at 6°58′S and 110°25′E. Figure 1 shows the location of Semarang City. The city covers an area of approximately 373.7 km^2 and is primarily used for agriculture and fishery (46.2%), residential, industrial, public and commercial (40.5%), forest (4.63%), bare land (0.78%) and others landuse (7.92%; Anonymous 2000). The Northern part of the city is a coastal plain while the Southern part is a higher ground. The elevation level of this city varies from about 0–453 m.

Semarang coastal areas faced land subsidence and tidal inundation (Marfai 2003b, 2004; Marfai and King 2007a, b). The high tide caused the inundation of coastal settlement and productive agriculture (Marfai et al. 2005, 2006; Marfai and King 2007b). The effect of

Table 2 Minimum DN values of land and maximum DN values of sea area

		Landsat images	
		MSS 1972 Band 4	ETM 2001 Band 4
DN value	Min land	5	35
	Max sea	3	29

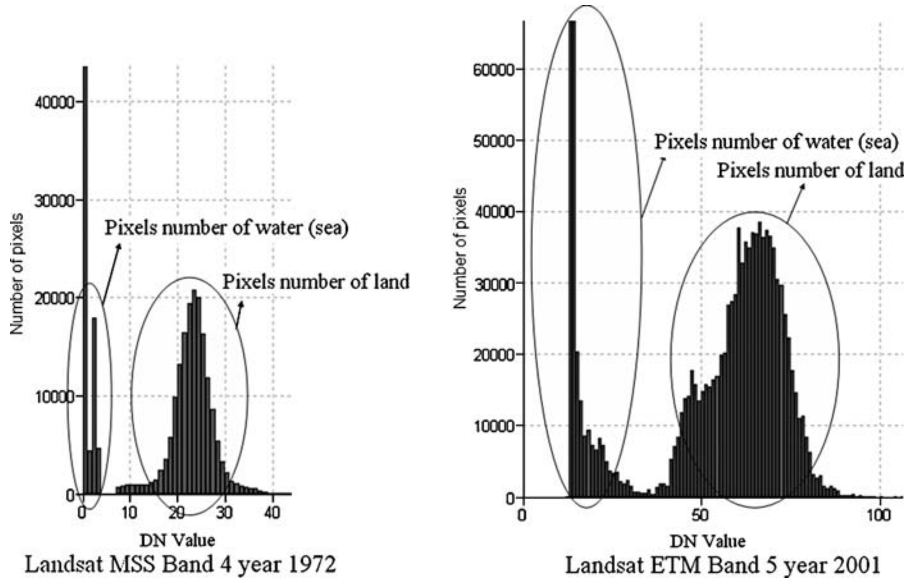


Fig. 5 Histogram analysis of band 4 Landsat MSS and band 5 Landsat ETM

the coastal inundation is predicted even worse with the prediction of sea level rise (Marfai and King 2007c).

Methodology overview

Following the growing availability of satellite images and GIS technique, numerous researches have been carried out to delineate water from the land. A scheme to detect coastline change using digitization of multitemporal images was presented by Mazian et al. (1989) and Eloushy and Tolba (2004). Aerial photograph and topographic map can provide an overview in a shorter time than the possible used methods of field surveying and ground control point using GPS tool.

Beyond manual detection and visual interpretation, several techniques using digital number (DN) value

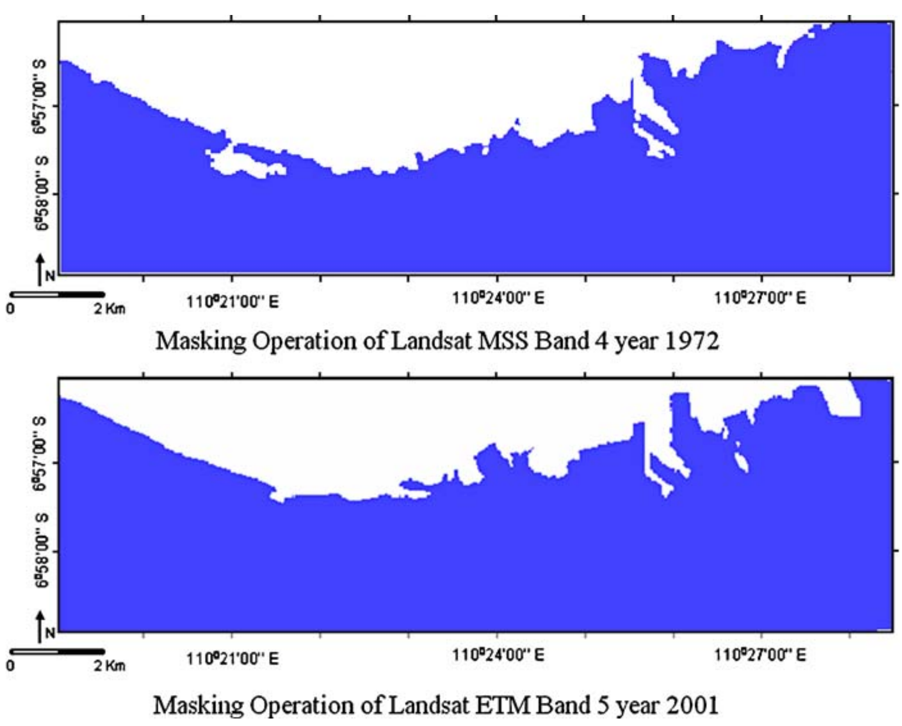


Fig. 6 Result of masking operation

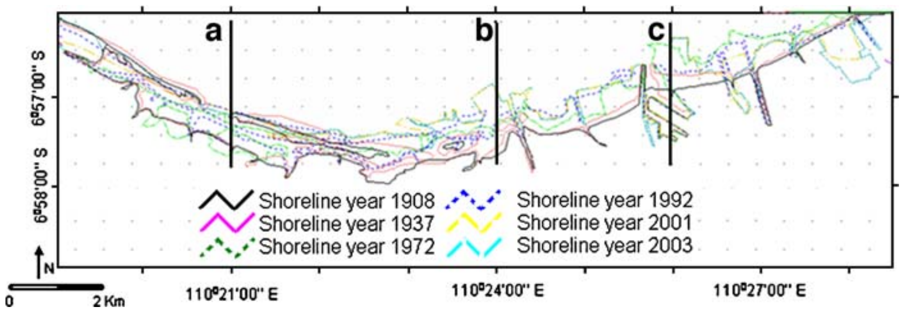


Fig. 7 Shoreline maps during period 1908–2003

analysis have been reported. The most common are density slicing of images (Bagli and Soille 2003). Whithe and El Asmar (1999) introduced an algorithm to deviate the water from the land based on solely on spectral analysis on individual pixels without taking into account of the texture, shape, morphology, and context of regions in the images. Furthermore, delineation of the water bodies from landsat have also been applied by various researchers, e.g., by Frazier and Page (2000); Yanli (2002), and Marfai (2003a). They found that simple density slicing of the Landsat, especially TM band 5 successfully detected wetland and water bodies. The DN threshold method is also often used for change detection. Liu and Jezek (2004) automated extraction of coastline from satellite imagery by canny edge detection using DN threshold. Chalabi et al. (2006) had used pixel-based segmentation on Ikonos image using DN threshold. The partition of the land and sea boundary was done using pseudo color which exhibits a strong contrast between land and water features.

In spite of the technique and approach to shoreline monitoring and delineation, no single method has been implemented that is free from major disadvantages (Mills et al. 2005). Using high resolution provides a useful solution, but is more costly and takes along process for the image enhancement. Using a topographic map proves easy for recognizing areas and delineation, but it is not always available on high scales. Combining heterogeneous remote sensing images and GIS data in change detection has great application potential, especially for the long term monitoring considering the availability of the dataset such as those in our case. An integration of technique, namely semi-manual delineation, DN value analysis, and masking operation has been made on the present research.

Dataset

Due to the lack of the homogeneous fine-resolution dataset, shoreline changes mapping of Semarang coastal area has been done using various multi-sources spatial data. Limited time series data are available in digital topographic maps for the year 1908, 1937, and 1992; digital Landsat MSS image for the year 1972; and Landsat ETM the year 2001; as well as Ikonos imagery for the year 2003. Scanned and geo-referenced digital topographic maps with the scale 1:50,000 are available in 5 m of pixel resolution. Meanwhile Landsat images are available for band 4 MSS and band 5 ETM. Ikonos image is available on panchromatic with 1 m of pixel resolution. Table 1 shows the attributes of the dataset.

Data processing and analysis

In the present research, change detection has been determined at the information-level domain instead of

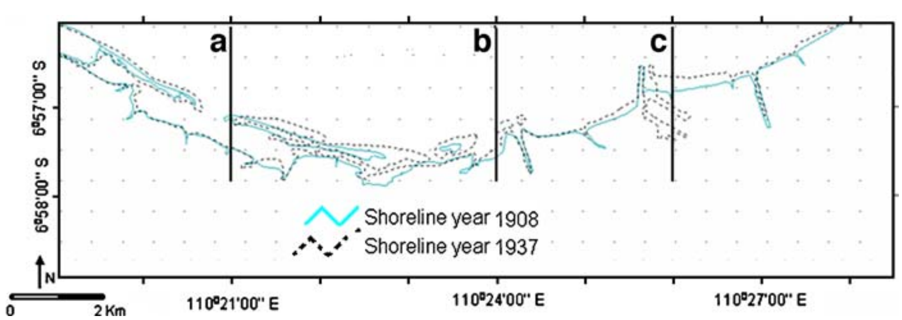


Fig. 8 Shoreline maps of the year 1908 and 1937

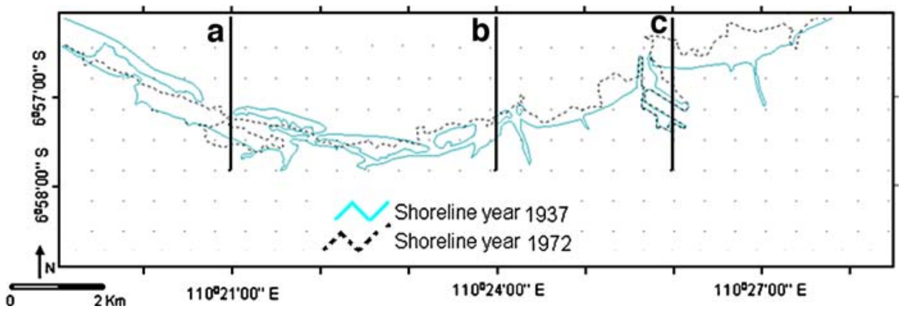


Fig. 9 Shoreline maps of the year 1937 and 1972

data-level domain. According to Armenakis et al. (2003) if we compared data of the same nature, i.e., data-series of homogeneous satellite images, the change detection can be determined at the data level domain while, when comparing heterogeneous dataset (e.g., Landsat ETM, Landsat MSS, Topographic map and Ikonos image), the change detection is performed at the information level domain. The data-level domain refers to comparison of pre-processed data and the information-level domain refers to comparison of analyzed data. For the latter, some data processing needs to be done prior to change detection. However problem related scale variability, such as accuracy remains. Xiaodong et al. (2006) noted that the problem might be limited by improving the geo-registration accuracy. In addition, Chalabi et al. (2006) demonstrated the monitoring shoreline using various scale of images. He improved the resolution of the aerial photography by scanning with 2 m resolution of pixel. It provided the detailed feature for analysis.

Detail pre-processing steps including the geo-referencing process were beyond the scope of this research. The geo-reference and ancillary data gathering has been done by previous research (Sutanta et al. 2003). Ancillary data sets for the processing were GPS points collected from the field and Topographic maps. A Garmin Map handheld GPS was used to collect GPS point in the field. The accuracy obtained, as shown by the receiver, is between 3 and 6 m. This accuracy is still far below the pixel size of the image.

Visual interpretation and delineation has been applied to Topography maps and Ikonos using vector operation. Topographic map has appropriate scanned resolution with 5-m resolution and therefore is convenient for using zoom in tool for the screen digitizing. The topographic maps with scale 1:50,000 have feature generalization compared to other sources. To obtain more detail results, topographic maps have been registered in a good accuracy by Sutanta et al. (2003) and scanned with pixel resolution of 5 m. As it is noted by Xiaodong et al. (2006) and Chalabi et al. (2006) problem related scale might be limited by improving the geometric co-registration accuracy and by scanning data with high pixel resolution. Even though this step was not solved the entire problem related scale, it provide detail feature for visual analysis and avoid an unnecessary mis-delineation.

Digital number value analysis for the Landsat images comprise three stages, namely (1) image enhancement, (2) image processing by masking using map calculation, and (3) shoreline delineation based on the masking maps (Marfai 2003a). Image enhancement has been done using linear stretching in order to obtain better visualizations. A linear stretching is a stretch method by which all values in an input map

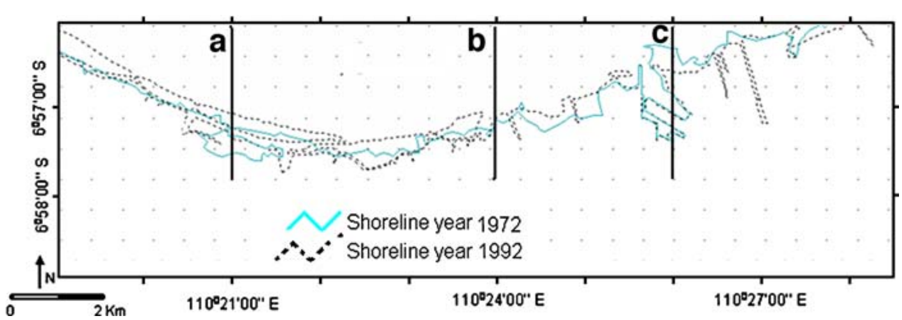


Fig. 10 Shoreline maps of the year 1972 and 1992

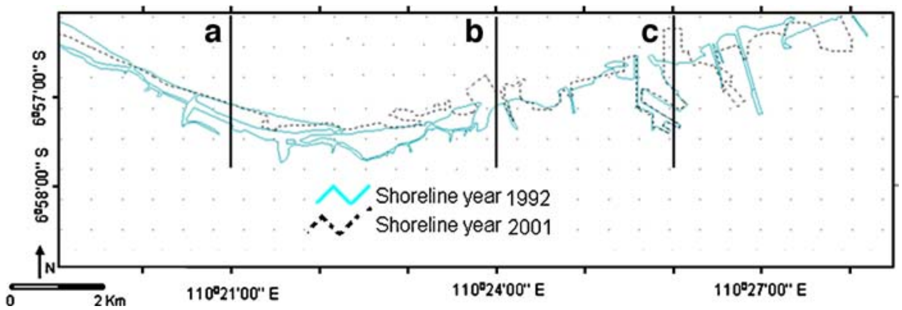


Fig. 11 Shoreline maps of the year 1992 and 2001

are converted into new values in an output map by using one formula. Masking operation has been applied in order to distinguish between land and water (sea) area. Digital number value has been observed using image histogram for Landsat images. Masking operation has been done using "iff" function in ILWIS Software. The formula to distinguish between land and water is shown as follows:

$$\text{Outputmap : iff band } n < \text{maximum pixel value of the sea, then sea, else land} \quad (1)$$

Where Outputmap: map result of calculation, Iff: statement iff function, Band n: band of Landsat which is used for operation, Maximum pixel value of the sea: maximum pixel value of the sea from histogram analysis, Then sea: the number which is to replace the pixel value of the sea, and Else land: the number which is to replace the pixel value of the land.

Once the masking operation is finished, the shoreline delineation can be created based on the masking map. GIS superimpose method has been used to identify the shoreline dynamic as well as detection of the sedimentation and erosion processes of the surface area. For this purpose, the dataset should be in vector format and have the same geo-referenced. Map overlay has been applied in order to identify land-sea changes on the area during period 1908–2003. Detail flowchart of the methodology is shown in Fig. 2.

Result and discussion

Visual interpretation and shoreline delineation has been conducted for topographic maps Year 1908, 1937, 1992 and Ikonos image Year 2003. Shoreline in Year 1908, 1937, 1992, and 2003 are shown in Fig. 3. Digital number value analysis of the spectral value of the Landsat images has been done in order to identify the boundary of the DN value of water and land. Some factors may cause inaccuracies when analyzing land water boundary, among others, are (1) due to the suspended sediment along the coast, hence DN value between land and water is quite close, and (2) a lot of plant and vegetation on surrounding coastal area bring impacts on the DN value of the images. To minimize the inaccuracies, image enhancement and filtering have been applied for band 4 of Landsat MSS and band 5 of the Landsat ETM (Fig. 4). Histogram analysis has been applied to dividing sea and land areas by recognizing maximum value of water and minimum value of land (Table 2). Histogram analysis of band 4 of Landsat MSS and band 5 of Landsat ETM are shown on Fig. 5. Furthermore, masking operation has been used by "iff" function in ILWIS

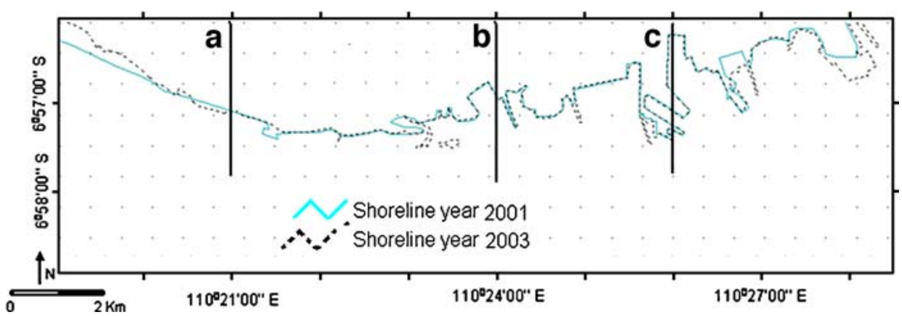


Fig. 12 Shoreline maps of the year 2001 and 2003

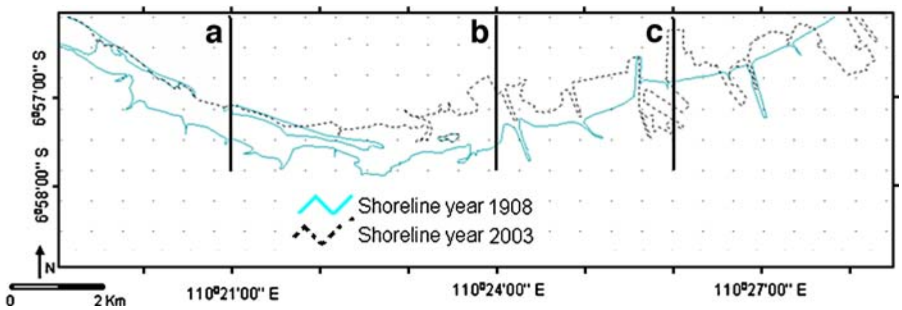


Fig. 13 Shoreline maps of the year 1908 and 2003

software for Landsat Year 1972 and 2001 and the result is shown in Fig. 6. The shoreline maps for the Year 1972 and 2001 can be generated from the results of the masking operation in which the boundary between land and sea is clearly shown.

Superimposed techniques have been carried out for all the segment maps from 1908 to 2003. The six segment maps have been obtained for comparing the shoreline on the chart (Fig. 7). Three selected profiles were selected across the shorelines (profile A, B, and C) to make easy in understanding the comparison and detection of change. The profiles have been placed based on the differences of geomorphological aspects and land cover features. Profile A is located in the natural shore nearby lagoon, tombolo, and sandbar. This area is also dominated by coastal vegetation cover. Profile B is located in the river mouth area with several man-made structures such as dyke and floodway canal. This area is dominated by sedimentation material from the upper catchment area. Meanwhile profile C is located in the man-made infrastructure such as land reclamation, harbor, and its supported structures.

During the period between 1908 and 1937, the shoreline extended about 0.5–1 km. In this period appeared small island; tombolo; lagoon; and sandbar in the Western part of the studied area. Longshore sediment from the mouth of the river plays an important role for the development of the tombolo, lagoon and sandbar (Fig. 8, profile A). Due to the development of the urban area since 1900s, several industrial estates and settlements located on the coastal area followed by beach-land reclamation lead to shoreline change. This feature was clearly shown in the Eastern part of the shoreline Year 1937 (Fig. 8, profile C). In addition, the pattern of the Tanjung Mas port harbor already appeared.

The resulted coast-wide patterns of shoreline changes in the Year 1937–1972 revealed that significant erosion occurred along the coast. The eroded sand moving by waves comes from the NE, generating westward-flowing long shore currents to the West wherein deposition occurs along the lagoon. Furthermore, the erosion process also took place on the small barrier/island in front of the lagoon. The erosion processes of the winds accumulate in great volumes of sand. Some of these sediments are transported into the lagoon causing sedimentation.

From 1937 to 1972, it can be seen that the tombolo and lagoon in the Western part of the study area was decreasing (Fig. 9, profile A). The shoreline of the year 1972 sifted to the sea, it was predicted that the area surrounding the island was buried with the sediment from the land and created the new land as a

Table 3 Estimated shoreline dynamic on the three observation profiles

Profile	Change of the coastline in meter					
	1908–1837	1937–1972	1972–1992	1992–2001	2001–2003	Total
A	+2	−25	+201	+2	+2	+182
B	+58	+177	+178	+221	0	+634
C	+265	+527	−461	+609	+5	+945

+Sedimentation; − erosion

recent sediment coast. The extended land appeared on the profile C in Fig. 9 which was expected due to sedimentation process during the period 1937–1972.

During the period between 1972 and 1992 generally the shoreline shifted to the sea, especially in the Western part and changed the form of the tombolo and small barrier (Fig. 10, Profile A) and even new tombolo appeared in area between Profile A and B. Rate of sediment transport in these areas are considerably high. However, several places eroded about 500 m to the land (Fig. 10, area between profile B and C). It implies also the decreasing coastal and low-lying area.

In 1992–2001, part of the shoreline, especially on the Eastern part, sifted to the land (profile C in Fig. 11). It indicated that strong erosions occurred. Meanwhile in the Western part, which is shown by profile A, the sedimentation occurred and the shoreline extended to the sea. The sediment was probably due to the landuse change and uncontrolled erosion on the upland area.

Period of 2001–2003 is the shortest period. The shoreline in this area did not change too much and it was considered the stable period (Fig. 12). Man-made infrastructure can be found along the coast, e.g. dyke, land reclamation, extended harbor, and jetty. For the long period of almost 100 year, the shoreline area extended to the sea as a result of man-made infrastructure and natural process such as sedimentation. Comparing to the shoreline from 1908 to 2003, the coast shows wide patterns of changes (Fig. 13). The measurement of the shoreline dynamic on the three observed profile have been made using measure-distance facility on the GIS software. These measurements revealed that significant sedimentation occurred in almost every period, except in the year 1937–1972 in profile A that was dominated by erosion process for about 25 m and in the year 1972–1992 in profile C that was dominated by erosion process for about 461 m (Table 3).

Conclusion

Shoreline dynamic mapping is very valuable in regards to coastal hazard assessment. The shoreline mapping gives contribution to the morphological dynamic and their process in the coastal area. As an example, nowadays Semarang coastal and low-lying areas are suffering from land subsidence and tidal inundation. The new residential areas and industrial estates are located in the coastal and low-lying areas with recent material from sedimentation. It is on this recent sediment deposit, as can be seen from shoreline dynamic in the year 1908–2003, where the land subsidence and tidal inundation are occurring.

Historic rates of shoreline change provide valuable data on erosion and sedimentation trends and permit limited forecasting of shoreline movement. Multi sources spatial data analysis can be considered promising method regarding lack of homogeneous data sources in the long period of time. However, further issues remain, as it is mentioned by Mills et al. (2005) that in all change detection methods, whether the results correspond to reality and the errors in data sources as well a data registration are not falsely categorized as change. It should be noted that the good accuracy is influenced not only by the coastline extraction method, but also by the geo-referencing accuracy of the sources images. Although the result is satisfactory, some further enhancements related geo-processing should be made for a future version.

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