



# Geoprocessing of High Resolution Imageries for Shoreline Extraction in the Process of the Production of Inland Electronic Navigational Charts

JACEK ŁUBCZONEK, Szczecin, Poland

**Keywords:** shoreline extraction, mathematical morphology, electronic navigational charts, image processing

**Summary:** At present, for map elaboration, remote sensing images are used very frequently. By using different methods of image processing, the process of developing the map can be automated, mainly due to the reduced time required to obtain geographical objects in vector form. The paper presents a method for the extraction of shorelines by using high resolution images. The extraction process by using geoprocessing tools of the ArcGIS software is exemplarily illustrated. Because GIS or remote sensing software can have several geoprocessing tools, it is important to investigate the set of tools proposed by the software developer that can be used for image processing. Based on this study, an image geoprocessing routine is proposed, which uses methods such as classification, thresholding, mathematical morphology, and vectorisation. The target use of the extraction method is dedicated to the production of Inland Electronic Navigational Charts.

**Zusammenfassung:** Geoverarbeitung von hochauflösenden Orthophotos zur Extraktion von Uferlinien für die Herstellung von elektronischen Navigationskarten für die Binnenschifffahrt. Zur Erstellung von Landkarten ist derzeit die Fernerkundung häufig Mittel der Wahl. Unter Verwendung von verschiedenen Bildverarbeitungsverfahren kann die Erstellung von Landkarten automatisiert werden. Hierbei spielt die automatische Erkennung geographischer Objekte eine zentrale Rolle. In diesem Artikel wird die Extraktion von Uferlinien aus hochauflösenden Bildern thematisiert. Anhand eines Beispiels wird der Extraktionsprozess von Uferlinien unter dem Einsatz von Geoverarbeitungswerkzeugen der ArcGIS-Software illustriert. Da solche GIS- oder Fernerkundungssoftware über verschiedene Werkzeuge zur Verarbeitung von Geodaten verfügt, ist eine Prüfung der vom Software-Hersteller angebotenen Werkzeuge zur Bildverarbeitung von Bedeutung. Aufgrund der durchgeführten Prüfungen wurde ein Verfahren zur Bildverarbeitung vorgeschlagen, das solche Verfahren, wie z.B. die Klassifizierung, die Segmentierung, mathematische Morphologie-Analyse und Vektorisierung benutzt. Das vorgeschlagene Verfahren kann bei der Herstellung von elektronischen Navigationskarten für die Binnenschifffahrt herangezogen werden.

## 1 Introduction

Navigation charts are a part of geoinformation systems (VETTER et al. 2012). Remote sensing imagery is one of the main sources of data used in chart production (ŁUBCZONEK & WŁODARCZYK 2010). Remote sensing imaging gives a better insight into the mapping area,

has a high information capacity and enables chart creation at large scales. Due to the large information capacity, often various methods are used for image processing which are designed to automate the extraction of certain objects. The basic methods already include thresholding and classification, which allow the separation of basic land cover classes. The

current GIS software in addition provides ever-increasing data processing capabilities. It allows for automation, i.e. the creation of data geoprocessing processes, which include a number of consecutive image operations, for example, classification, operations of mathematical morphology, vectorisation, and cartographic generalisation.

One of the basic data used in the production of electronic navigational charts are photogrammetric materials in the form of high resolution orthophotos. Presently, for the purpose of such studies, orthophotos are used with a resolution of several centimetres or decimetres. These materials are characterised by great detail and have a high potential for interpretation. For the production of electronic charts, an important object type is the shoreline which is topologically linked with many other map objects (IENC 2015). Currently, the development of navigation charts is also supported by other studies, such as the reduction of large datasets (STATECZNY & WŁODARCZYK-SIELICKA 2014), fusion of hydrographic data (STATECZNY & BODUS-OLKOWSKA 2014), the development of numerical models of the sea bottom (ŁUBCZONEK 2004, MALEIKA et al. 2012), uncertainty of bathymetric data (WAWRZYNIAK & HYLEA 2014), or waterborne laser scanning as the potential source of chart creation (BURDZIAKOWSKI et al. 2015).

The problem of identifying the shoreline of watercourses by using photogrammetric material is mainly challenged by the presence of objects such as vegetation, trees, buildings, engineering constructions, or shallow waters

in its neighbourhood. In case of a good demarcation of water and land, the fundamental problem may be the length and shape of the shoreline, which translates into a significant increase of time required for accurate manual digitization. For the purpose of chart production, it is therefore essential to automate data processing, which should shorten the time needed to develop data and improve its accuracy.

## 2 Shoreline Extraction Cases

Based on the literature, it can be concluded that different case studies deal with the extraction of the shoreline. These case studies are directly related to the extraction of coastlines or objects which are circumscribed by coastlines, for example, river, land or water bodies. Generally, the case studies utilize different methods for the shoreline or land-water area extraction and various other types of remote sensing data. They address different types of aquatic environments or shorelines, and consider different types of water surface textures. Tab. 1 summarises the case studies found in literature (BUONO et al. 2014, ZHANG et al. 2013, SHI et al. 2010, SAKURAI-AMANO et al. 2002, ZHANG & WANG 2010, LI et al. 2011, HE et al. 2012, YIN & HE 2011, CHEN 2009, KHURSHID et al. 2012, LIU & NIE 2012, DANDAWATE & KINLEKAR 2013, KUPIDURA 2013, YANG et al. 2014, SILVEIRA & HELENO 2009, BASELICE & FERRAIOLI 2013, KLINGER et al. 2011, SCHMIDT et al. 2013).

**Tab. 1:** Case studies related to the shoreline extraction problem.

	Case studies	Type
1	Extraction method	Edge detection functions, image classifications, artificial intelligence (neural networks and fuzzy logic), morphological operations, watershed algorithm, snakes algorithm, combinations of some above methods, other proposed methods
2	Data	Three-band satellite images, SAR and InSAR data (radar data), DEM, LIDAR data
3	Area of extraction	Sea, riverbeds, flood extend areas, tropical forest, inlands, lakes, icy terrain
4	Shore type	Muddy, sandy, rocky, artificial, icy, also in some cases not specified
5	Water texture	Partly wavy water, water with glares
6	Water type	Sea, river, lake, mixture of river and sea water

Based on analyses summarized in Tab. 1, study cases were related to dedicated areas of the shoreline extraction. Some environmental aspects suggest that the proposed methods have an individual character and are applicable in specified terrain or water body environment.

In this paper, a method of the shoreline extraction is proposed and associated with the acquisition of data in the production process of electronic chart for inland navigation. This concerns navigable watercourses, which are the primary type of data in such electronic charts. The extraction process was realised in the ArcGIS software by combining thresholding and classification methods with morphological operations followed by a vectorization. For the study, high resolution orthoimages were used ranging from visible to near infrared spectra.

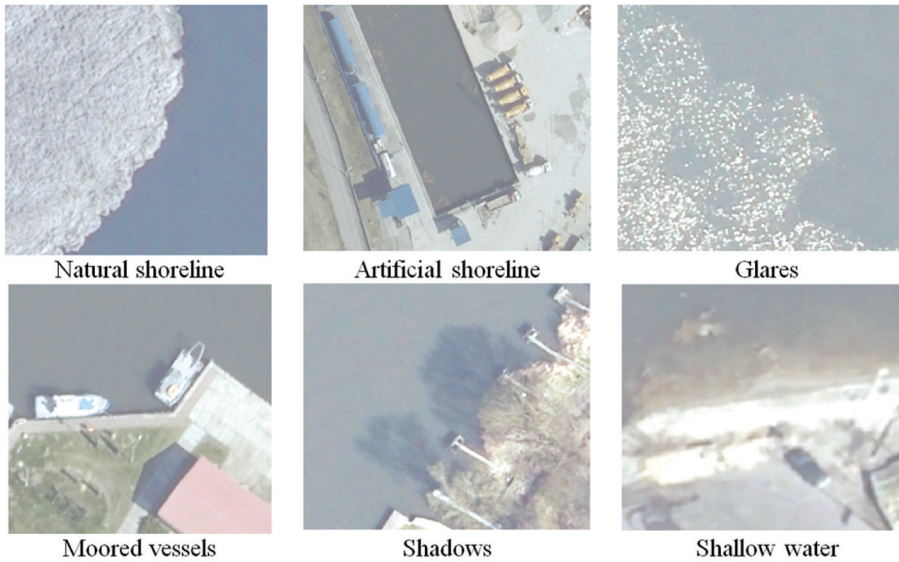
### 3 Study Area

Orthoimages prepared from aerial photographs were used. The analysis was based upon two three-band combinations: RGB

(red, green, blue) and CIR (near infrared, red, green), one four-bands combination: RGB-NIR (red, green, blue, near infrared), and four single bands: R (red), G (green), B (blue), and NIR (near infrared). The spatial resolution of the images was 0.15 m. Such resolution is useful for the proper identification of smaller objects like piles, stones, fishing poles and the identification of various types of shores, i.e., sandy, artificial (both, in good condition and ruined), or overgrown with vegetation. The range of the orthoimage is illustrated in Fig. 1. Fig. 2 illustrates some special cases, which were taken into consideration during the shoreline extraction process. The first case is the natural shoreline, which represents about 90 percent of the investigated shoreline. This line has an irregular shape that is mainly caused by naturally overgrown reeds. The next case is the artificial shoreline, which often occurs in urbanised areas. This shoreline is characterised by regular shapes and straight sections, but sometimes there are places, where the constructions are ruined and therefore the shoreline has an irregular shape. The other cases include water with glares, moored vessels, shadows on the water, and shallow



Fig. 1: Example of an orthoimage used in the study (East Oder River, Szczecin-Podjuchy).



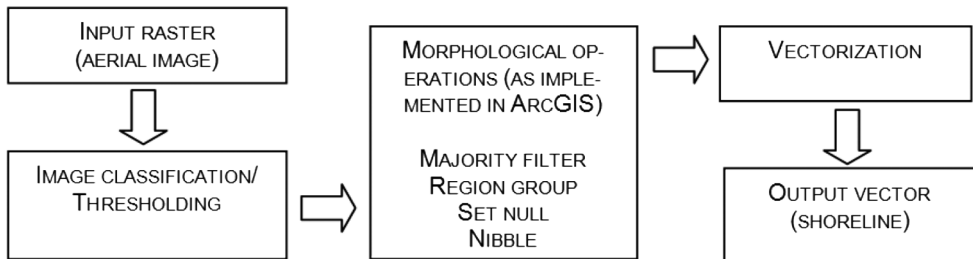
**Fig. 2:** The different cases considered in the process of the shoreline extraction.

waters. Shadows may cause problems in the process of proper separation of water and land due to the confusing spectral signatures. Glares and vessels should be removed from the water area, because they do not belong to the shoreline class. Shallow waters in turn are sometimes problematic during visual interpretation. Therefore, similar problems may exist during the extraction process.

#### 4 Processing of the Images

A multi-stage data processing using ArcGIS software was used for the shoreline extraction. The first stage involved the separation of ba-

sic classes needed for the shoreline extraction (land and water) from the image. For this purpose thresholding and classification of image content were utilized. The next step included the generalisation of the image content by using mathematical morphology operations, which have been identified as one of the methods for edge detection in remote sensing images (KAUR & GARG 2011). The vectorisation of the shoreline was the last step. The general schema of shoreline extraction is presented in Fig. 3. The extraction of a coastline in ArcGIS software can also be automated. For this purpose, the ArcGIS Model Builder can be applied, which allows automated data processing.



**Fig. 3:** General schema of the shoreline extraction.

### 4.1 Thresholding and Classification of Image Content

For thresholding natural breaks methods (JENKS & CASPALL 1971) were used, by means of which the division of image content into two basic classes (land and water) based on one threshold value was performed. For the classification of the image content, both methods were tested, supervised Maximum Likelihood classification and unsupervised Iso Cluster classification.

In order to evaluate the methods, a visual criterion was used, under which the course of natural and artificial shoreline, separation of glares on the water surface, separation of moored ships, lack or existence of shadows situated on the water, and the quality of the extracted line in the area of shallow waters were estimated. Therefore, a point scale ranging from 1 to 5 and additional object weights were introduced (Tab. 2). The point scale and the weights made it possible to compare the effectiveness of the methods. The major weight was applied to the natural shoreline due to its importance – it represents approximately 90% of the completely mapped shoreline. The smaller weights were applied to the objects, proportionally to their importance in the extraction process.

The results of the visual assessment are illustrated in Fig. 4 as the final number of points determined on the basis of the visual assessment. Thresholding and classification methods have been tested on the following compositions: RGB, CIR, RGB-NIR (without thresholding due to the 4 bands) and the individual spectral bands: R, G, B, NIR. For the

Tab. 2: Objects weights for visual assessment.

Type of object	Weight
Natural shoreline	0.50
Artificial shoreline	0.10
Ships	0.05
Shallow waters	0.10
Shadows	0.15
Glares	0.10

three-band combinations, thresholding was performed on their colour maps. The comparison of the assessment results shows that better results were achieved by using unsupervised classification (4 cases) or thresholding (3 cases). The best results were achieved applying the different methods to the near infrared band only. In other words, the best distinction between water and land was observed in the NIR band.

Visual comparison of the results showed that natural and artificial shorelines were determined best over the entire length using the NIR band only. By doing so, there was no significant effect of shadows on the water. Ships and glares were correctly mapped in the sense of their separation from water area. The only drawback of using this method (NIR band) was a poor demarcation of water and land in shallow waters. Because the shallows are small in number in the area under consideration, this drawback was not so important in that study. Tab. 3 shows selected cases of correct and incorrect separation of land and water with a short description of the examples.

The studies also analyzed the computer's processing time and the time for manual dig-

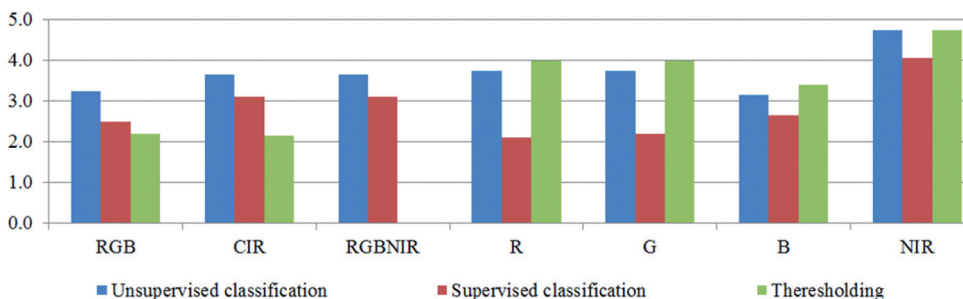
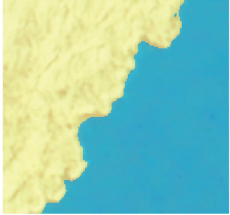

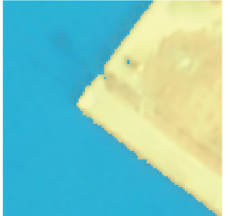


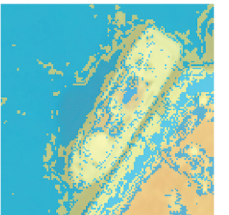


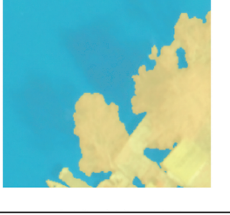


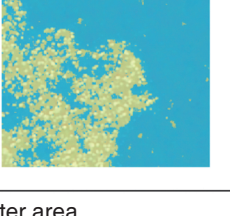


Fig. 4: Cases included in the extraction process of shoreline (vertical scale without dimension).

Shoreline type	Correct separation	Incorrect separation
<p><b>Natural shoreline</b></p> <p>Left: unsupervised classification, NIR image – good separation between water and land area</p> <p>Right: supervised classification, RGB image – land class overlaps water area</p>		
<p><b>Artificial shoreline</b></p> <p>Left: unsupervised classification, NIR image – good separation between water and land area</p> <p>Right: supervised classification, RGB image – land class overlaps water area, especially in the area of shadows</p>		
<p><b>Vessels</b></p> <p>Left: unsupervised classification, NIR image – good separation between vessel and land area</p> <p>Right: thresholding, CIR image – poor results, mixed pixels of water and land area</p>		
<p><b>Shallow water</b></p> <p>Left: unsupervised classification, B band image – partially good results, but mixed water and land class</p> <p>Right: unsupervised classification, NIR image – poor result, land class significantly covers shallow water area</p>		
<p><b>Shadows</b></p> <p>Left: unsupervised classification, NIR image – good result, water class does not contain shadows cast by the trees</p> <p>Right: supervised classification, RGB-NIR image – poor result, shadows classified as land class</p>		
<p><b>Glares</b></p> <p>Left: unsupervised classification, NIR image – good result, glares classified as small pixel groups</p> <p>Right: supervised classification, RGB image – poor result, glares classified as solid class of land</p>		

**Tab. 3:** Examples of correct and incorrect separation of land and water area.

itization. Geoprocessing of the analysed image, which consisted of 6942 columns and 5021 rows (about 35 Mbytes per channel), lasted about 19 minutes. Manual digitization of the same area took about 42 minutes. Hence, compared to the computer geoprocessing, operator performance of vectorization was twice as long. The processing was performed on a PC with an i7 processor and 16 GB RAM.

#### 4.2 Image Morphology Operations

In the next step, the classified images were processed by using morphological operations. The processing aimed at the removal of misclassified data (mainly holes in a class of land) as well as filtering out irrelevant pixel clusters or single pixels (for example, from the water area). Those clusters represent objects such as ships and glares. Additionally, unwanted pixel clusters can originate from different kinds of port infrastructure, for example dolphins or buoys, as well as from vegetation. In the present study, the following morphological operations as implemented in ArcGIS software were combined: Majority Filter, Region Group, Set Null, and Nibble (ArcGIS 2016). The functionality of these geoprocessing tools is defined as follows:

- Majority Filter – removal of individual cells, which are misclassified in the image; parameters used: (1) Number of neighbours – FOUR.
- Region Group – assigning an identifier for separated group of each cell for later removal; parameters used: (1) Number of neighbours – FOUR, (2) Zone grouping method – WITHIN.
- Set Null – creation of mask of separation cells regions smaller then threshold, which

should be removed; parameters used: (1) Input false raster or constant value -1, (2) Expression – a logical expression that determines the input cells that are to be true or false – value was set as  $< 35,000$ . Finally, the use of the Set Null tool created a mask for clusters with a pixel number less than 35,000.

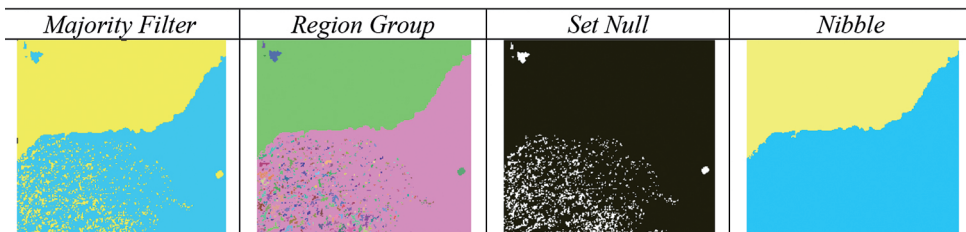
- Nibble – eliminates small regions by using mask and replaces them with the closest cell with its value by using previously created mask. This tool allows for the final elimination of the so called holes in the land and water classes.

All morphological operations, that are included in the geoprocessing tools of ArcGIS, are illustrated in Tab. 4. The Majority Filter tool removed single misclassified pixels, the Region Group tool grouped clusters into zones, and the Set Null tool created a mask from clusters with pixel quantity less than the threshold. The threshold was manually set by the operator by analysing previously grouped clusters. The last tool, Nibble, fills the holes based on previously created masks. After this operation, two classes, water and land area, were finally extracted.

A part of the classified image before and after the application of the morphological operations is presented in Fig. 5. It describes the filling of holes in the land and water objects. Holes are incorrectly classified objects, or objects not associated to the main class, here: water or land. Generally, they are objects with smaller size or smaller number of pixels, such as glares, dolphins (port infrastructure), separated ships, and small floating objects.

The last stage of data processing was vectorisation, which is the conversion from a raster to a vector model. This conversion is performed by using the tool Raster To Polygon,

**Tab. 4:** Result raster images after the application of the geoprocessing tools.





**Fig. 5:** Left: classified image before the application of morphological operations, middle: classified image after morphological operations, right: vectorized shoreline(subset).

whereas the option ‘Simplified output’ was selected to obtain smooth shoreline shapes, i.e., vectorised lines as close as possible to the object cells edge. Vectorisation ends the process of automated data processing. The shorelines can be stored in a database after the necessary corrections.

## 5 Accuracy Assessment

In order to assess the accuracy of the shoreline extraction, the mean and maximum errors were calculated from 33 test points which were chosen randomly from the study area. These points were evenly distributed across the coastline to cover the entire area. Three points were located in the areas of shallow water, and 30 test points in the rest of the study area. Such division was justified by the fact that on the basis of visual analysis, the greatest disparity in areas with shallow water was found. Errors were also compared with results of manual classification. The results were summarised in Tab. 5 as average (EA) and maximum (EM) errors. Errors represent residuals (distances) between test points and their orthogonal projections onto the extracted or manually elaborated shoreline. Examples of extracted shorelines are illustrated in Fig. 6.

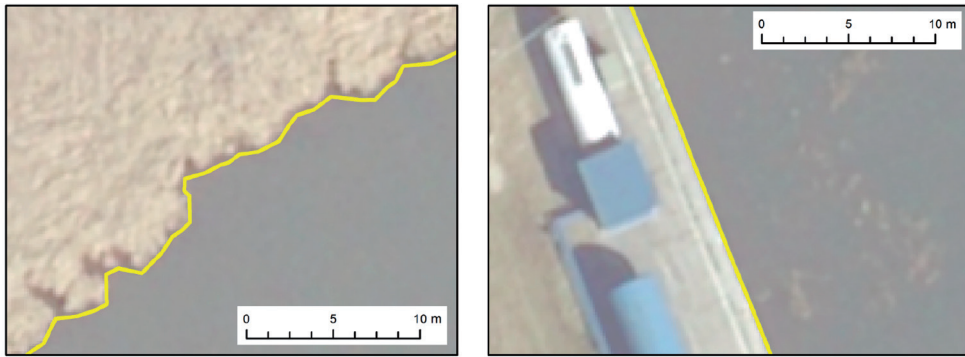
Noticeable problems occurred in shallow water areas, which has been discussed previously, and in areas, where land objects overlap with the area of water or in the presence of engineering structures. These land objects comprised the crowns of trees, fishing piers, and bridges. In some cases, the outline of the shoreline was drawn along the contours of ships. When the ship was separated from the water after classification or thresholding of the image, it was removed in the process of geoprocessing. The same happened with smaller objects, such as ship mooring devices and various floating objects.

Also, based on the visual assessment, extracted lines were compared with the lines elaborated manually. Measurements of sections of wrongly extracted shorelines were performed manually. For the unsupervised classification and the thresholding, the failure to comply with the reference line was 8.6% and 7.5%, respectively. It can be assumed that the average discrepancies were 8%, which means a correctness of the extraction on the level of 92%. The biggest problems for the methods arose at the sections of shorelines shaded by buildings and partially flooded areas (Fig. 7). In this case, the spectral signatures of water and land were similar, which in turn reduced the accuracy of the classification and

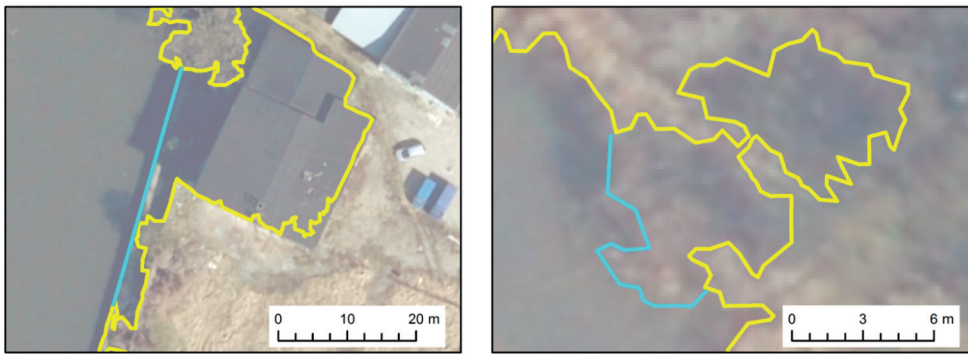
**Tab. 5:** Accuracy assessment of extracted shoreline.

	Shallow water		Other cases	
	EA	EM	EA	EM
Manual classification	0.72 m	1.34 m	0.40 m	0.67 m
Thresholding	1.09 m	2.48 m	0.09 m	0.23 m
Unsupervised classification	1.74 m	3.18 m	0.10 m	0.31 m





**Fig. 6:** Examples of extracted shorelines, left: in non-urbanised areas (natural shoreline) and right: in urbanised areas (artificial shoreline).



**Fig. 7:** Cases of misclassified shoreline (blue line), left: roof and shaded berth as part of the water, right: shaded or wet area as part of the water.

subsequently the demarcation between land and water.

## 6 Summary

Based on the study it can be concluded that high resolution images can be utilized to extract shorelines for electronic chart production. In this case, it is also important to appropriately select the spectral bands. Based on our study it can be stated that the best results were obtained when using NIR images. In the proposed method of distinguishing between two the basic objects (land, water), the best results were obtained by using an unsupervised classification and thresholding. The application of the suggested morphological operations, implemented as ArcGIS tools, extracted the final shoreline as a vector feature. The

shoreline extracted in the presented case study is characterised by a proper shape, which determines the precise boundary between water and land. The calculated average error had a value of about one pixel with a maximum of two pixels. The demanded accuracy listed in the minimum content of Inland ENC's for the shoreline acquisition is less than 1 m (Inland-ECDIS 2015), while the maximum error in our study was only 0.31 m. In the study case, the correctness of the extraction was estimated at 92%. Taking into account the extent of a watercourse in the development of electronic charts, this result is very good. Based on the study, difficulties were experienced in extracting the shoreline in areas of shallow water, which may practically limit the usage of this method in such cases. Regarding the analysed water area, such shallows were of marginal percentage. Hence, this influence was

regarded negligible. The proposed method is also less time consuming compared to manual digitization, which is an important factor during data elaboration for large areas. In order to shorten the processing time, the content of the image can be reduced to the area of interest, e.g. rivers or lake zones.

## References

- ArcGIS, 2016: ArcGIS Desktop Help, version 10.3.1.
- BASELICE, F. & FERRAIOLI, G., 2013: Unsupervised Coastal Line Extraction From SAR Images – Geoscience and Remote Sensing Letters, *IEEE* **10** (6): 1350–1354.
- BUONO, A., NUNZIATA, F., MASCOLO, L. & MIGLIACIO, M., 2014: A Multipolarization Analysis of Coastline Extraction Using X-Band COSMO-SkyMed SAR Data – Journal of Selected Topics in Applied Earth Observations and Remote Sensing, *IEEE* **7** (7): 2811–2820.
- BURDZIAKOWSKI, P., JANOWSKI, A., KHOLODKOV, A., MATYSIK, K., MATYSIK, M., PRZYBORSKI, M., SZULWIC, J., TYSIAC, P. & WOJTCOWICZ, A., 2015: Maritime Laser Scanning as the Source for Spatial Data – Polish Maritime Research **22** (4): 9–14.
- CHEN, A., 2009: River Extraction Based on Knowledge and Fuzzy Classification. – Sixth International Conference on Fuzzy Systems and Knowledge Discovery **3**: 438–441.
- DANDAWATE, Y.H. & KINLEKAR, S., 2013: Rivers and Coastlines Detection in Multispectral Satellite Images Using Level Set Method and Modified Chan Vese Algorithm – 2nd International Conference on Advanced Computing, Networking and Security (ADCONS): 41–46.
- HE, X., HUANG, N. & HUANG, D., 2012: Research and application on digital river network extraction modified routing algorithm based on DEM. – International Conference on Systems and Informatics (ICSAI):1728–1731.
- IENC, 2015: Encoding Guide for Inland ENCs. – 2.4.0 ed., Inland ENC Harmonization Group.
- INLANDECDIS, 2015: Open ECDIS Forum 2015. – <http://ienc.openecdis.org> (25.6.2016).
- JENKS, G.F. & CASPALL, F.C., 1971: Error on Choroplethic Maps: Definition, Measurement, Reduction. – Annals of the Association of American Geographers **61** (2): 217–244.
- KAUR, B. & GARG, A., 2011: Mathematical morphological edge detection for remote sensing images. – 3rd International Conference on Electronics Computer Technology (ICECT) **5**: 324–332.
- KHURSHID, M., HASNAT, K. & FAISAL, M., 2012: River extraction from high resolution satellite images. – 5th International Congress on Image and Signal Processing (CISP): 697–700.
- KLINGER, T., ZIEMS, M., HEIPKE, C., SCHENKE, H. & OTT, N., 2011: Antarctic Coastline Detection using Snakes. – PFG – Photogrammetrie, Fernerkundung, Geoinformation **6** (6): 421–434, Schweizerbart Science Publishers, Stuttgart.
- KUPIDURA, P., 2013, Distinction of lakes and rivers on satellite images using mathematical morphology. – *Biuletyn WAT* **LXII** (3): 57–69.
- LI, Z., LI, M., CHENG, L., LIU, Y. & CAI, W., 2011: Coastline monitoring with CEBERS 02B HR high-resolution data. – 19th International Conference on Geoinformatics:1–5.
- LIU, F. & NIE, Y., 2012: River System Extraction Based on BP Neural Network and DEM Data – International Conference on Industrial Control and Electronics Engineering (ICICEE): 41–43.
- LUBCZONEK, J., 2004: Hybrid Neural Model of the Sea Bottom Surface. – Artificial Intelligence and Soft Computing, *ICAISC* **3070**: 1154–1160, Lecture Notes in Computer Science, Springer.
- LUBCZONEK, J. & WŁODARCZYK, M., 2010: Charting of the shoreline of inland waters using digital remote sensing images. – *Muhammad Scientific Journals* **22** (94): 53–58, Maritime University of Szczecin, Poland.
- MALEIKA, W., PALCZYNSKI, M. & FREJLICHOWSKI, D., 2012: Effect of density of measurement points collected from a multibeam echosounder on the accuracy of a digital terrain model. – *Intelligent Information and Database Systems*: 456–465, Springer Berlin und Heidelberg.
- SAKURAI-AMANO, T., ONUKI, S. & TAKAGI, M., 2002: Automatic extraction of rivers in tropical rain forests from JERS-1 SAR images using spectral and spatial information. – IEEE International Geoscience and Remote Sensing Symposium, *IGARSS '02* (6): 3429–3431.
- SCHMIDT, A., ROTTENSTEINER, F. & SOERGEL, U., 2013: Water-Land-Classification in Coastal Areas with Full Waveform Lidar Data. – PFG – Photogrammetrie, Fernerkundung, Geoinformation **2013** (2): 71–81, Schweizerbart Science Publishers, Stuttgart.
- SILVEIRA, M. & HELENO, S., 2009: Separation Between Water and Land in SAR Images Using Region-Based Level Sets. – *Geoscience and Remote Sensing Letters* **6** (3): 471–475.

- SHI, Y., WU, L., BIAN, F. & LI, X., 2010: Automatic coastline extraction in remotely sensed images using improved watershed algorithm. – 2nd International Conference on Information Science and Engineering (ICISE): 2671–2674.
- STATECZNY, A. & BODUS-OLKOWSKA, I., 2014: Hierarchical Hydrographic Data Fusion for Precise Port Electronic Navigational Chart Production. – *Telematics – Support for Transport, Communications in Computer and Information Science* **471**: 359–368.
- STATECZNY, A. & WŁODARCZYK-SIELICKA, M., 2014: Self-organizing Artificial Neural Networks into Hydrographic Big Data Reduction Process, Rough Sets and Intelligent Systems Paradigms. – *Lecture Notes in Computer Science* **8537**: 335–342.
- VETTER, L., JONAS, M., SCHRÖDER, W. & PESCH, R., 2012: Marine Geographic Information System. – KRESSE, W. & DANKO, D. (eds): *Springer Handbook of Geographic Information*: 439–460.
- WAWRZYŃIAK, N. & HYLA, T., 2014: Managing Depth Information Uncertainty in Inland Mobile Navigation Systems. – *Lecture Notes in Computer Science, Rough Sets and Intelligent Systems Paradigms* **8537**: 343–350.
- YANG, H., LEE, D.-G., KIM, T.-H., SUMANTYO, J.T.S. & KIM, J.-H., 2014: Semi-automatic coastline extraction method using Synthetic Aperture Radar images. – 16th International Conference on Advanced Communication Technology (ICACT): 678–681.
- YIN, J. & HE, F., 2011: Researching the method of coastline extracted by remote sensing image. – International Conference on Remote Sensing, Environment and Transportation Engineering (RSETE): 3441–3444.
- ZHANG, X. & WANG, Z., 2010: Coastline extraction from remote sensing image based on improved minimum filter. – Second IITA International Conference on Geoscience and Remote Sensing (IITA-GRS) **2**: 44–47.
- ZHANG, H., ZHANG, B., GUO, H., LU, J. & HE, H., 2013: An automatic coastline extraction method based on active contour model. – 21st International Conference on Geoinformatics (GEOINFORMATICS) **2013**: 1–5.

## Address of the Author:

PhD Dr.-Ing. Jacek Łubczonek, Maritime University of Szczecin, Institute of Geoinformation, ul. Żołnierska 46, 71-250 Szczecin, Poland, Tel./Fax: +48-91-48-77-177, e-mail: j.lubczonek@am.szczecin.pl.

Manuskript eingereicht: März 2016

Angenommen: Juni 2016