On the migration and characteristics of near shore sandbars

Author: *Arno Jacob Timmer | 920429833050*

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On the migration and characteristics of near shore sandbars

Arno Jacob Timmer

Registration number 92-04-29-833-050

Supervisor:

Ron van Lammeren

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Abstract

A cross section of a coastal profile is a descending slope, often with upward deviations. The upward deviations are near shore sandbars and they majorly influence the energy and angle of waves that reach the shore. The dynamics of these sandbars have been studied intensely. The way they are studied changes with technology. Because of the increase in both temporal and spatial extent of the data, GIS offers an opportunity to study the sandbars over a large amount of time and a large spatial extent. This thesis proposes a method to identify sandbars along the Dutch North Sea coast, and calculates the volume, shape and movement within coastal areas and coastal regions. Sandbars are detected based on the direction of their slope, the aspect. The volume is calculated by summing the volume above the lowest point in the sandbar. Sandbar shape is quantified by calculating the basin elongation. The movement within a coastal area is calculated by using the average location of a sandbar in grid cells. All sandbar characteristics are compared among coastal areas and coastal regions.

The sandbar detection method influences the calculated volume and the identified shape. The volume is theoretically slightly under estimated, although the found volumes were close to the volume numbers found in literature. The theoretical underestimation is non-structural and depends on the slope of the shore. The shape of sandbars is found to be more elongated than round. The movement profiles identified in this research show a distinct spatial pattern within the studied coastal areas. The resulting cross shore movement is not significantly different from movements found in literature.

Preface

Writing this preface I am putting the last hand on this master thesis. I learned a lot while doing this thesis research, not only about sandbars but more importantly about how to learn and about myself. Due to a hard deadline I became familiar with ‘working really hard’. I should have done this before. I enjoyed this greatly at some moments and less at other moments... At the end of the day this whole time I needed for my thesis is a period I will contently look back at.
Obviously I could have never done this without a few people.

I want to thank Ron van Lammeren for his supervision. At times I thought that his way of supervising was not the right style for me, but ultimately I learned a lot about myself, arguably more important than the whole thesis thing. Next to Ron I have to thank the whole MGI staff during courses before my thesis, during the failed tries for a thesis before and for walking in your rooms with questions about general GIS stuff (John Stuiver) or random statistical questions (Sytze de Bruin).

I want to thank ‘the thesis room’ and the MGI community. I really appreciated the way how we work together and next to each other. There was always time to blow of some steam or ask how they would have done something. This contributes, I think, greatly to the whole study program and definitely to my thesis. I want to thank the people who proof read my thesis or parts of it in special: Gijs Peters, Jorn Habes, and Robbert-Jan Joling.

For more than six years now I have lived in the same house. During the thesis process I was not present that much. Nonetheless I was supported in any way possible by my housemates. My thesis was proofread by Taric Schrader, who replied to my e-mail within 24 hours (?!) and Jasper Snellen voluntarily offering to spend a few hours.

Of course I want to thank Jaela Arian, who stood by me during some moments where I could not see the end of this whole thing, I will not forget all these dinners and walks we did! Thank you for that, but also for the proof reading. I don’t understand how you notice that I wrote ‘the x direction’ in the beginning and ‘the X direction’ twenty pages later.

Last but not least I want to thank my family. Not only during this thesis process but during my whole learning career. Starting with writing lessons while on holiday in Italy, during my high school, when my learning was maybe more important to my mother than to me, and still going on. I am not sure if I would ever show any interest in sandbars if it was not for you (yes this is definitely a good thing!). I want to thank my father for his always down to earth but hardly ever wrong advices. I want to thank my sister for standing all the fights I had during your easy dinners or other moments where you probably did not really feel like me having to admit another 4 without a good reason.

I hope that you will find this thesis interesting, that you will learn something and that all my hard work will be appreciated by my supervisors and examiners!

Arno Jacob Timmer
Wageningen, *08/11/2017*

Arno

Contents

1 Introduction

Sandbars play an important role in coastal protection. The migration of sandbars changes the shape of the sea bed, which influences in what direction, and with how much power waves and currents reach the shore (Short 1999). Sandbars closer to the coast and low sandbars let waves come on shore with more power than higher sandbars further from the coast (Cambazoglu 2009). Next to the direct influence on waves, sandbars store sediment which supports dune development and beach supplementations, which in their turn, protect the coast (Aleman et al. 2011). Especially in low lying countries like the Netherlands the protection of the coast becomes more and more important due to the expected sea level rise. This vulnerability was one of the reasons to study the coast of the Netherlands more thoroughly. One of the products of this is the JARKUS dataset, yearly measurements of the bathymetry of the North Sea close to the Dutch shore from 1963 to 2016 and still ongoing.

Sandy beaches have a shape that is formed by the characteristic wave climate of this beach or coast. Wave climate is a term that describes the nature of incoming waves at a coastline. Generally it is described by monthly or annually averaged conditions (Short 1999). The cross section of a coast profile can roughly be described by a function proposed by Dean (1991). Deans' formula predicts a rough estimate of the cross section of the bottom profile. This predicted part is the part where sediment transport is dominated by currents rather than wave energy. At this section the timescales of changes are smaller than at the area where the coast is dominantly influenced by wave energy (Davidson-Arnott 2013; Reeve et al. 2007). The coast profile proposed by Dean is descending curve. Sandbars are upward deviations in this curve. They consist of sediment particles which are transported by water motions in the ocean. Sediments may erode on one side of the sandbar and accumulate on another side. This process can be interpreted as movement of a sandbar and is then known as sandbar migration. Next to migration this sediment transport can also cause the shape of a sandbar to change. Migration along the coast is known as long shore movement and movement towards and away from the coast is known as cross shore movements (Davidson-Arnott 2013). Studies suggest that most sandbars migrate considerably during a year (Albuquerque et al. 2011; Exon 1975; Exon 1975; Walstra et al. 2012; de Vroeg 1987; Elgar et al. 2001; Damsma 2009). Sandbars closer to the coast migrate and change faster than sandbars further from the coast (Davidson-Arnott 2013). However, Reeve et al. (2007) illustrate that there is no direct correlation between distance from the coast and scale of variation in time. They found that rapid changes at one location can occur without changes at another location at the beach profile. Above mentioned literature illustrates that scale is an important issue while studying sandbars. With increasing extents of datasets in both the temporal as the spatial domain, possibilities of studying sandbars on nationwide scale arise. This thesis research will focus on studying sandbars along the entire Dutch coast.

In section 2 literature will be summarized, definitions will be given and the problem will be evaluated. In section 3 the research questions will be presented. Section 4 will go in depth on the methods that are used. Firstly detection and characterization methods will be evaluated and secondly the bar characteristics will be compared. In section 0 the obtained results will be presented, following the structure of the research questions. Section 6 will discuss the obtained results and emphasize the weaknesses of the used methods. Section 7 will summarize the conclusions that are drawn. Section 8 gives recommendations for further research.

2 Problem Definition

Near shore sandbars have been studied for many years (Exon 1975; Carter & Balsillie 1983; Konicki & Holman 2000). From the 50's to the 70's the focus of research was mainly on positioning on short time scales due to the available equipment at the time. With the development of equipment also the focus of research changed. The time scales prolonged but also the focus changed to the processes behind the migration of bars and sediment transport. With the introduction of large wave tanks in the 90's long term behaviour of sandbars can be studied with limited scaling issues (Wang et al. 2003; van Thiel de Vries et al. 2008). Hell et al. (2012) reviewed the use of geospatial bathymetric data in the Baltic Sea and concluded that the availability of bathymetric data with a high resolution in both time and space could be of benefit to marine research.

Although the rise of technology motivated studying of sandbars on a larger scale, research is still done on smaller scales. Albuquerque et al. (2011) studied small scale sandbar migration at the coast of Brazil. They looked at daily profiles of a coast with near shore sandbars. They found varying sandbar widths from 80 to 137 meter and found an average migration of 4.08 meter per day.

Aleman et al. (2011) summarize several bar systems from literature. Single or multi-bar systems exist but also straight or crescentic systems. Most of these characterizations are two dimensional based. Aleman et al. (2011) did a three-dimensional larger spatial scale characterization of the Gulf of Lion based on a small temporal scale (one week long), with daily light detection and ranging (LIDAR) measurements.

The sandbars along the Dutch shore show a motion known as the Dutch model (Aagaard 2013; Wijnberg & Kroon 2002; Aleman et al. 2013). The bars show a cyclic behaviour. The inner bar, closer to the coast, move seawards becoming the outer bar while newer sandbars take the place of the former inner bar (Ruessink & Kroon 1994; Aleman et al. 2013). Studies that found this system studied parts of the Dutch coast.

de Vroeg (1987) studied the migration of sandbars using the JARKUS dataset. He found a multi barred system with an off shore moving trend which corresponds with the findings of Ruessink and Kroon (1994). Data was used from 1970 to 1985 and the area of the Dutch coast between 'De Hoek van Holland' and 'Den Helder'. This part is the coastal region Noord Holland in this research as is defined in section 4.2. He found a difference in migration velocity between the north and the south of the area. In the north a migration velocity in the order of 10 to 20 meter per year and in the south a velocity of 50 meter per year. North of IJmuiden he found bars which would disappear while migrating and highly fluctuating migrating velocities. As bar characteristics he calculated differences between the tops of sandbars ranging from 200 to 400 meter.

Small scale studies suggest a known motion of sandbars along the Dutch coast, similar to other coasts. de Vroeg (1987) found varying migration speeds on a larger scale questioning the homogeneity of the Dutch system. Hell et al. (2012) emphasize the possibilities of the use of geospatial bathymetric information such as digital elevation models (DEMs). Wijnberg & Kroon (2002) stress the importance of studying long term behaviour of sandbars based on time series rather than on intensive field work.

The recognition of sandbars in digital elevation models can be interpreted as image classification. In image classification there are many techniques which can be divided in three major categories: unsupervised classification, supervised classification and object based image analysis (OBIA).

i) Unsupervised classification segregates the data into clusters without additional user input, the classifier will not add a label to detected classes. A user has to add meaningful labels to the detected classes.
ii) In supervised classification representative areas are selected by the user that indicate which classes have to be classified. The software classifies the image based on these training samples to find similar areas that will get the same label.

iii) OBIA classifies pixels in context to other pixels where both supervised and unsupervised classification evaluate each pixel separately. Hay and Castilla (2008) state that the use of OBIA in GIS and remote sensing is different than OBIA in ordinary images. They propose the term Geographic Object Based Image Analysis, GEOBIA. They defined this as follows: "*Geographic Object-Based Image Analysis (GEOBIA) is a sub discipline of Geographic Information Science (GIScience) devoted to developing automated methods to partition remote sensing imagery into meaningful image-objects, and assessing their characteristics through spatial, spectral and temporal scales, so as to generate new geographic information in GIS-ready format.*"

Supervised classification would need a trainings dataset of sandbars. The number of images needed to train the classifier is larger than it is realistically possible to create in the available time. Pure unsupervised classification is not suitable for the identification of sandbars because we are interested in exactly two classes, sandbars and not sandbars. The method will detect classes of no interest. Sorting this result will be relatively time intensive. Both supervised and unsupervised classification are not suitable for detecting sandbars.

As this study is proposing a method for automated partition of DEM data into meaningful objects, sandbars, this method can be classified as GEOBIA.

To study the spatial variation of characteristics of sandbars, this thesis research evaluates the volume, shape and movement of sandbars along the entire Dutch coast. GEOBIA is used to detect sandbars in DEMs and will calculate the characteristics. The overall method that is used in this thesis is summarized in the flowchart in Figure 1.

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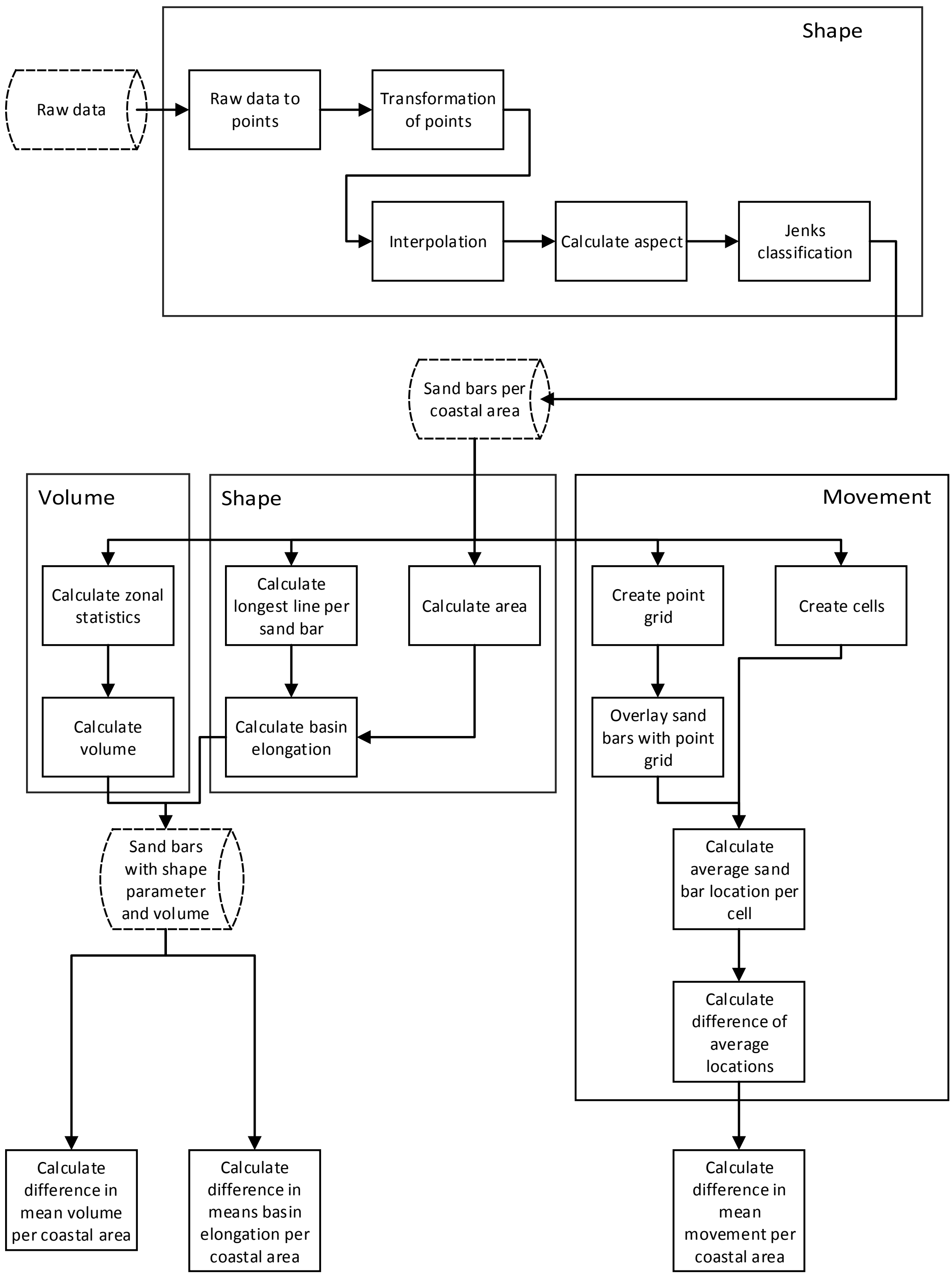

Figure 1: Flowchart. A visualization of the methodology used in this research. The colours indicate different research questions. Conclusions will be drawn from the statistics database. The concluding step is not visualized in this flowchart.

3 Research objective and related questions

In this thesis research a method will be proposed to recognize and characterize near shore sandbars by using the JARKUS dataset. The differences of sandbars in volume, shape and movement in different coastal areas and regions will be compared. The objective of this research is to propose a method to define and characterize near shore sandbars in a large area over a large amount of time.

The following research questions will be answered:

1. How to detect and characterize near shore sandbars in the JARKUS dataset using GIS techniques?
   1.1. How to detect near shore sandbars with the use of the JARKUS dataset?
   1.2. How to characterize the volume, shape and movement of near shore sandbars?
2. How do the recognized characteristics vary in the defined coastal areas and regions along the Dutch coast?
   2.1. Does the volume of near shore sandbars vary in the defined coastal areas and regions along the Dutch coast?
   2.2. Does the shape of near shore sandbars vary in the defined coastal areas and regions along the Dutch coast?
   2.3. How do long- and cross shore movement of near shore sandbars vary in the defined coastal areas and regions along the Dutch coast?

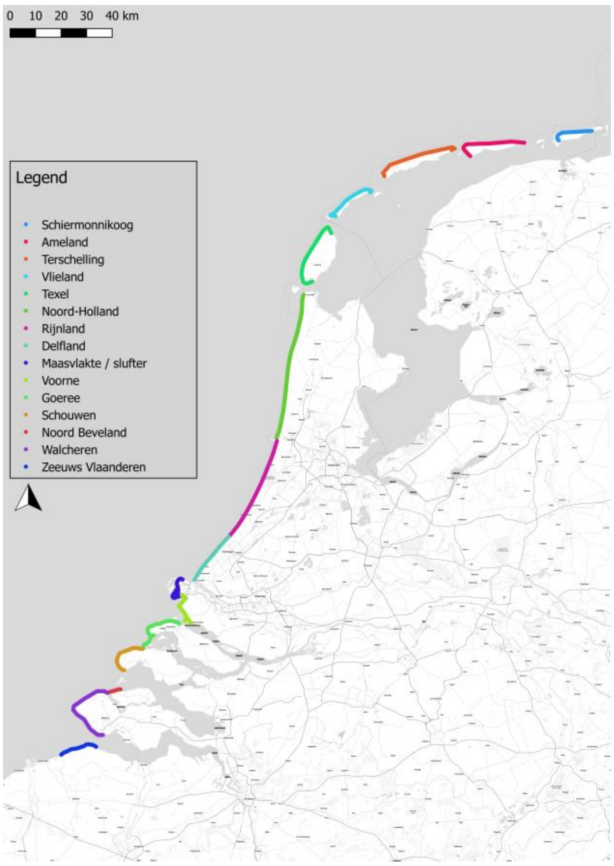

Figure 2: The fifteen Coastal Areas that will be studied in this research and the location of these

4 Methodology

In this section the strategy that is used to detect sandbars and the characterization of those will be discussed. Firstly the data that is used will be described in 4.1. The research area will be described in section 4.2. Section 4.3 will elaborate on the method that is used to recognize sandbars in five steps that are taken. Section 4.3.2 will go in depth about the characterization of the sandbars. Sections 4.3.2.1, 4.3.2.2 and 4.3.2.3 will treat the comparison of respectively the volume, shape and movement of sandbars within the coastal areas and regions.

4.1 Data

The raw data supplied by the Rijkswaterstaat consists of point data measurements in transects from the top of the first dune going seaward from 1965 to 2008. The length of the transects varies. Transects taken earlier are shorter and the lengths of transects varies within one year. All are between 800 meter and 3000 meters. The long shore distance between two transects is 200 meter. The points are supplied as a combination of a distance and a depth measurement. Together with an angle and an origin these can be turned into meaningful information. The transects contain both wet and dry measurements. Dry measurements being the height measurements above sea level. Before 1977 dry measurements were done by ground based surveying with an accuracy of 0.01 meter. From 1977 to 1996 dry measurements were made by aerial stereo photography with an accuracy of 0.1 meter and from 1996 until 2016 the dry measurements are measured by laser altimetry from aircraft with an accuracy of 0.1 to 0.15 meter. Wet measurements are measured by soundings from survey vessels and have an variable error of 9 cm. (Southgate 2011; Damsma 2009; RIKZ 1996).

The transects are divided in 15 coastal areas or in Dutch ‘kustvakken’. Each transect has an identification number which consists of the transect number and the coastal area number.

4.2 Area

The extent of this research is confined to the Dutch North Sea coast. The reason for this is the availability of the JARKUS dataset. The coastal areas as defined in the JARKUS dataset differ in size and shape. Clustering could be done based on similar coastal shape increasing sample sizes. This will result in more trustworthy results. Zeeland is the region with interrupted, relatively small heavily curved coastal areas including Maasvlakte, Voorne, Goeree, Schouwen, Noord Beveland, Walcheren, and Zeeuws Vlaanderen. Noord Holland is the region with straight uninterrupted coasts containing Noord-Holland, Rijnland and Delfland. Islands is the region consisting of the Dutch ‘Waddeneilanden’, the islands in the North of the Netherlands: Schiermonnikoog, Ameland, Terschelling, Vlieland, and Texel

4.3 RQ1 Detection and characterization of sandbars.

In this study sandbars were defined under the assumption that a coastal profile without sandbars is a curved, descending slope. The definition used in this study is as follows: *the area between a local minimum and local maximum height that faces shoreward with a minimum area of 150000 square meter which lie entirely below the sea level.* This definition simplifies the recognition process by setting a minimum size and defining simple recognizable boundaries. It neglects many features that are relevant in oceanography such as the real base of the sandbar, proper boundaries and wavelength. These features are nonetheless important but not in the scope of this research.

With exception of the parts where alternatives are mentioned, the recognition of sandbars is done using the programming language Python (van Rossum 1995) Many python modules have been used such as Fiona, Shapely, GDAL, Numpy, Pandas and

Geopandas. Spatial visualizations were primarily done using QGIS (QGIS Development Team - Open Source Geospatial Foundation 2009).

4.3.1 RQ1.1 Detection of sandbars

In Figure 1 the method used in this paper is visualized. In the following sections this will be discussed in more detail in the following order.

Before any processing can be done, the raw data is converted to workable point features. This is explained in detail in 4.3.1.2. To improve the model performance in the parts where the coast is curved, the points were transformed so that the transects run parallel to each other with the starting points at a straight line, this will be discussed in more detail in section 4.3.1.1. The points were aggregated so that the area of interest is specified. This area is saved as the mask, in this area all the calculations per point dataset will be done. The transects were then converted from points to lines which are used, together with the points, as input for the interpolating. Several interpolation techniques were compared, on which is elaborated in section 4.3.1.2. The TIN tool is the tool that is most suitable. The resulting triangulate interpolation network (TIN) is converted to a raster format so digital elevation model (DEM) calculations can be carried out. The raster is then filtered to remove artefacts and values above zero since these areas above sea level are not of interest for this study. The aspect is calculated as is elaborated in 4.3.1.4. The aspect will then be classified using the Jenks Optimization Method on which is elaborated on in section 4.3.1.5. The classification results in classes of direction which the slopes of the bathymetry point at. The dominant direction of the slope is facing away from the coast, the slopes facing the coast are the slopes of interest. Sandbars smaller than 150.000 square meter were filtered out. The resulting polygons were classified as sandbars.

4.3.1.1 *Transformation of points*

Before the sandbar recognition can be done, the measurement transects will be transformed. This is needed because the direction of the slope will be used to identify sandbars. Since the direction of the slope that we were interested in might change in a coastal area, detecting the direction of interest is not possible without transformation of these transects. When the transects run parallel the direction of interest is equal over a coastal area.

The coordinate system of the entire project is *'rd new',* therefor the map units of the project are metres. This makes it possible to add and subtract distances from coordinates in meters. This proves to be very useful in the following step.

The assumption is made that the shoreline of a coastal area is a continuous line

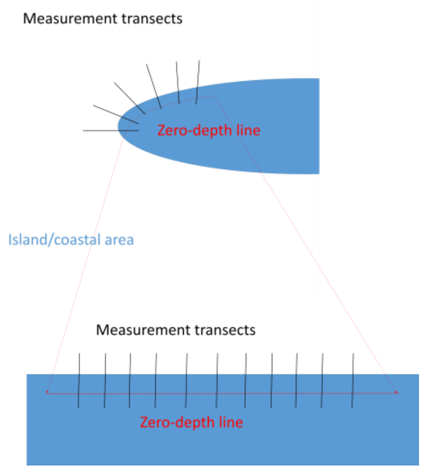

Figure 3: Visualisation of the transformation of the transects. A straight zero-depth line is created which the transects all pass. From this zero line the transects run parallel.

at depth zero of each transect. When the zero-depth points of each transect is identified a line can be constructed that can be straightened as is visualized in Figure 3. The zero-depth point was not necessarily measured in the JARKUS dataset. To create this point there has been linearly interpolated between the first occurrence of two points around zero. Since the cross shore distances were known between each point, the zero-depth point can be taken as origin of a transect. From the origin each transformed coordinate can be calculated for the transects.

To transform the line of zero-depth points the Y coordinates of these points need to be equal and the distances between the points need to be the distances between the points in the original situation. The long shore distances between the zero-depth points were calculated. The constant Y coordinate was taken from the first transect of a coastal area, the transect with the lowest transect id. The distance between the zero-depth points is cumulatively added to the X value of the initial point. Since the Y coordinate is equal for every zero-depth point, the zero-depth points lie on a straight line with a distance in between equal to the initial distance between the transect.

4.3.1.2 Raw text to XYZ data.

To understand the translation from the raw input data to the point data, some understanding about the structuring of the input files and measurements is necessary which is elaborated on in section 4.1.

The raw data consists of files and information about starting points and their angles of transects, which were supplied by Rijkswaterstaat which part of the Dutch ministry of infrastructure and environment. The text files containing the measurements are structured in a way that a header is followed by a number of rows with measurements. The header consists of coded information about the year, the coastal area and at which of the transects the measurements were taken in. The measurements are structured in pairs of two numbers. The first number is the distance from a starting point and the second number is a depth measurement.

The second file contains the starting point and angle of the measurements together with coded information indicating to which of the transects the information belongs.

During the conversion information of the two files is combined so that for each set of measurements a unique ID is created. This ID indicates from which year, which coastal area, and which transect in the coastal are the measurement is from. The transect ID is read from both files to obtain the distance, angle and origin from each point so that the location point is calculated. This information is stored in csv files so that for each coastal area, for each year a file is created storing the depth at unique locations in X, Y and Z coordinates.

4.3.1.3 Comparison of interpolation techniques

To detect sandbars a continuous height model is needed. This continuous data is created by interpolating between known heights as were created using the method elaborated in 4.3.1.2. The method that is used to interpolate between the measured points has a major influence the quality of the DEM that is used to detect the sandbars (Li & Heap 2014). To find the best technique five different interpolation methods were compared: Spline interpolation with and without barriers, the "topo to raster" tool and interpolation based in triangulate networks. All methods where carried out in ArcMap. All the methods that were used are deterministic interpolation methods. The advantage of this is that it is less time consuming than stochastic interpolation methods. The pixel size for all the interpolation methods is set to 30 m.

The natural neighbour (ESRI n.d.)method is an interpolation method where each unsampled point gets a value which is the weighted average of a number of neighbouring points. The method is relatively quick but is expected to perform worse than the rest of the methods.

Spline interpolation is an interpolation method that fits a plane mathematically so that known points lie on the plane (Wu et al. 2013). Spline interpolation is described by the ArcGIS documentation as follows: *"The spline bends a sheet of rubber that passes through the input points while minimizing the total curvature of the surface. It fits a mathematical function to a specified number of nearest input points while passing through the sample points. This method is best for generation gently varying surfaces as elevation, water table heights or pollution concentration."* The 'gently varying surface' criterion fits the purpose for this study.

The difference between the spline with barriers (ESRI n.d.) and the spline method is that the spline with barriers tool accept an input that specifies the outer boundaries of the area that is to be interpolated and the spline tool does not. This means that the interpolated raster will be masked after the interpolation is done using the spline tool, causing the tool to use values in its calculation that lie outside of

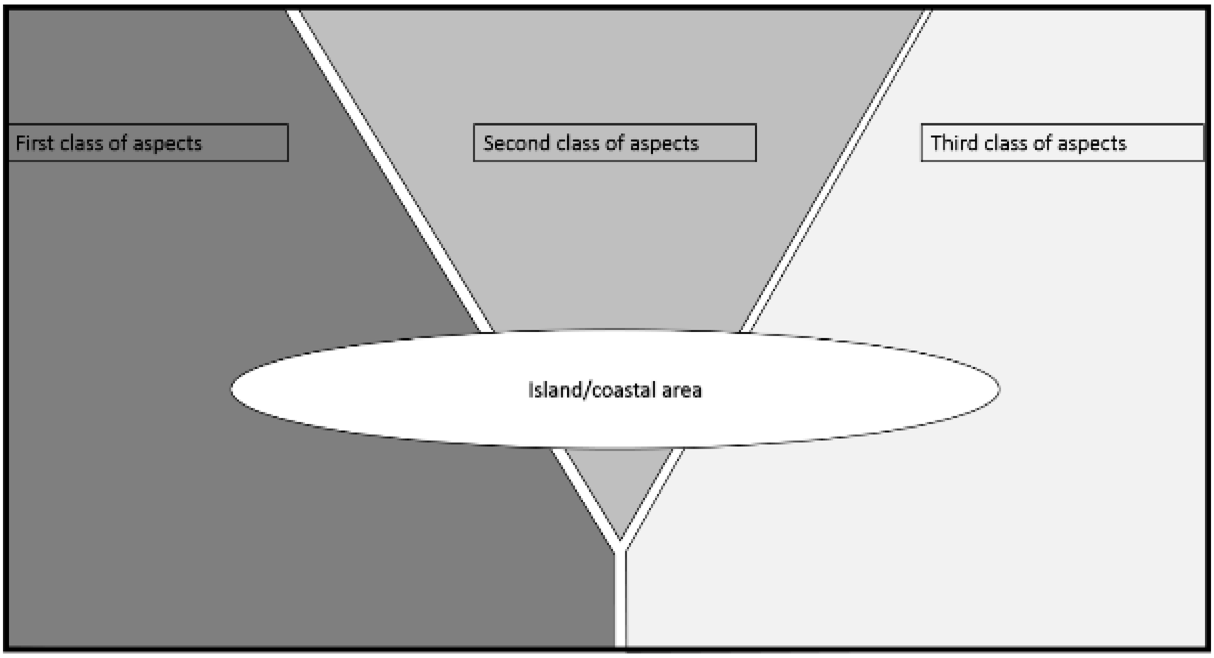

Figure 4: Sketch of Jenks Classification and how the aspects are separated in classes. Three classes are classified, where the first one contains the aspect directions from roughly north-west to south, the second class contains the directions north-west to north-east and the third class contains the directions north-east to south.

the area of interest. The spline tool is expected to deliver a less realistic output than the spline with barriers and will take longer to calculate.

The "topo to raster" tool is specifically developed to interpolate topographical surfaces. This means that the result of this interpolation is ensured to be hydrologically correct. It is based on the ANUDEM program that is developed by Michael Hutchinson**.** (Hutchinson 2011) "*It is essentially a discretized thin plate spline technique (Wahba 1990) for which the roughness penalty has been modified to allow the fitted DEM to follow abrupt changes in terrain, such as streams, ridges and cliffs.",* as is stated on the documentation of ArcMap (ESRI n.d.). Given the purpose that this method is developed for it is expected to deliver functional results.

The last method is interpolation based on Delaunay triangulation (Cignoni et al. 1998). Delaunay triangulation is widely used for representing terrains, for example in flight simulations and 3D games (Razafindrazaka 2009). The Delaunay triangulation creates relatively little small triangles compared to other triangulation techniques which has the advantage that it reduces calculation time and represents the terrain better.

4.3.1.4 ***Calculate aspect.***

a	b	c
d	e	f
g	h	i

Figure 5: context of pixel e. These pixels surrounding pixel e are used to calculate the direction of the aspect (ESRI n.d.).

For the recognition of sandbars a second order derivative of a DEM is used, the aspect. Since the nature of sea beds close to the shore is to have a slope facing the other direction than the land, the slopes facing the land indicate sandbars. The aspect was calculated using ArcMap's Aspect tool. This tool classifies the pixels in 360 different aspect classes (or degrees) depending on the 8 surrounding pixels.

The equation that is solved for each pixel is as follows:

Eq. 1
$$\frac{dz}{dx} = \frac{(c + 2f + i) - (a + 2d + g)}{8}$$

where *a, c, d, f, g, i* and *f* taken from Figure 5.

Only sandbars with an area larger than 150.000 square meter will be taken into account since this is how sandbars where defined in on page 9.

4.3.1.5 *Jenks Classification, selecting the correct aspect*

When the aspect is calculated, a decision has to be made about which of the 8 classes is relevant for this study. Since the orientation of the coast might change this is not always the same set of directions. To select the directions of the aspect that were relevant, Jenks natural breaks classification is used (Chen et al. 2013). The Jenks classification classifies the aspects in 3 classes. The Jenks classification minimizes the average deviation from the mean per class while maximizing the difference between mean of the class and the means of other classes. The three classes contain the following direction: first class contains the aspect directions from roughly north-west to south, second class contains the directions north west to north east and the third class contains the directions north east to south. Figure 4 contains a rough sketch of how the directions were divided in classes. The second class is the class that contains the aspects which indicates the sandbars and is of interest for this study.

4.3.2 RQ 1.2 Characterization of sandbars

Sandbar characteristics identified were volume, shape and movement. The following sections describe the strategies to identify these characteristics. To study the differences in characteristics at different larger regions within the Netherlands, coastal areas have been clustered as is elaborated on in section 4.2.

4.3.2.1 *Volume*

Demirci, Aköz, and Üneş (2014) list a selection of methods for the calculation of the volume of sandbars. These methods generally include parameters for sediment type and the period of sandbars. This research did not include these parameters because it focusses on studying the potential of using GIS in sandbar recognition. Further research needs to be done which method is most suitable for volume calculation of sandbars.

During this calculation the assumption is made that the base of the sandbar is as low as the lowest part of the sandbar. The sum of the sediment above this lowest point is the total volume of the sandbar, see Eq. 2, where V is the volume of a sandbar in cubic kilometres, H_{pixel} is the height given by a pixel value in meters, H_{lowest} is the lowest height given by a pixel value in meter and A_{pixel} is the surface area of one pixel in square meter.

Eq. 2
$$V = \sum H_{pixel} - H_{lowest} \cdot A_{pixel}$$

The statistics of the DEM on the locations of the sandbars were calculated using a tool developed by Matthew Perry (Perry 2013). It masks the raster with the polygons of the sandbars form the same location and year. The result is raster values only in the sandbars. The mean, min, max, standard deviation, sum and the count is then calculated and saved to a csv file. A loop is created to calculate all statistics for all sandbars.

Demirci, Aköz, and Üneş (2014) developed a conceptual model for sandbar volumes by proposing a function based on sediment characteristics and wave characteristics. The result of this function is a dimensionless parameter that expresses the volume of a sandbar dependent on the sediment size. To study the range of the calculated volume in this study, the volume will be compared with the outcome of the study of Demirci et al. The grain size that is needed to calculate bar volume will be taken from Guillén and Hoekstra (1996).

Sandbars larger than one cubic kilometre and smaller than one cubic meter were neglected. Sandbars lower than one cubic meter are assumed to be tiny ripples or irrelevant features and sandbars with volumes above one cubic kilometre are over three times the size as the largest sandbars found by Demirci, Aköz, and Üneş (2014) and therefor assumed to be errors in the detection.

4.3.2.2 Shape

Eq. 3 $$E = \frac{2\sqrt{A}}{L\sqrt{\pi}}$$ Basin Elongation (Schumm 1956)

Basin shape morphometry is a field of research that studies that shapes of hydrological drainage basins. (Bárdossy & Schmidt 2002) collected several basin shape parameters that can objectively compare shapes of basins without scaling issues. Due to the wide range of sizes of sandbars, one of these parameters were used in this research to quantify the shape of sandbars: basin elongation (*E*). *E* (Eq. 3) is the ratio of the longest line within a polygon divided by the diameter of a circle with the same area as the polygon (Schumm 1956). *E* quantifies how round a sandbar is. *E* of one indicates a round polygon. *E* going to zero would approximate a straight polygon. The basin elongation is chosen since the prime interest of the calculating the shape is quantizing how long and stretched a sandbar is. The longest length of a polygon is calculated using the script written by Roland van Zoest (see Appendix A – Roland van Zoest, Polyon spider (2017).

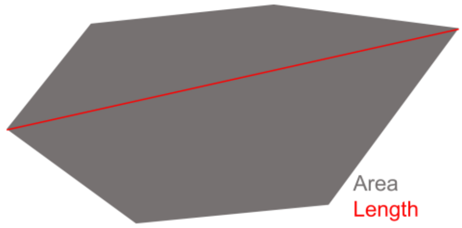

Figure 7: Visualization of the area (A) and longest length (L) in a polygon.

4.3.2.3 Movement of sandbars

For the movement of sandbars a method is developed that will not track single sandbars but will calculate a movement profile per area. The term movement is used to emphasize the fact that not the migration is studied but a general overview of the movement of sandbars within coastal areas or regions. In short the average location per pixel will be calculated and the difference between the location in one year and the following will be called movement as is shown in Figure 6.

The method that is used to calculate the movement is visualized in Figure 6. A regular spaced grid of points is created in a bounding box. This bounding box is equal for every set of sandbars. The grid of points will be overlaid by the sandbar polygons and all the points that lie without the sandbars will be erased. What remains is then a regular spaced

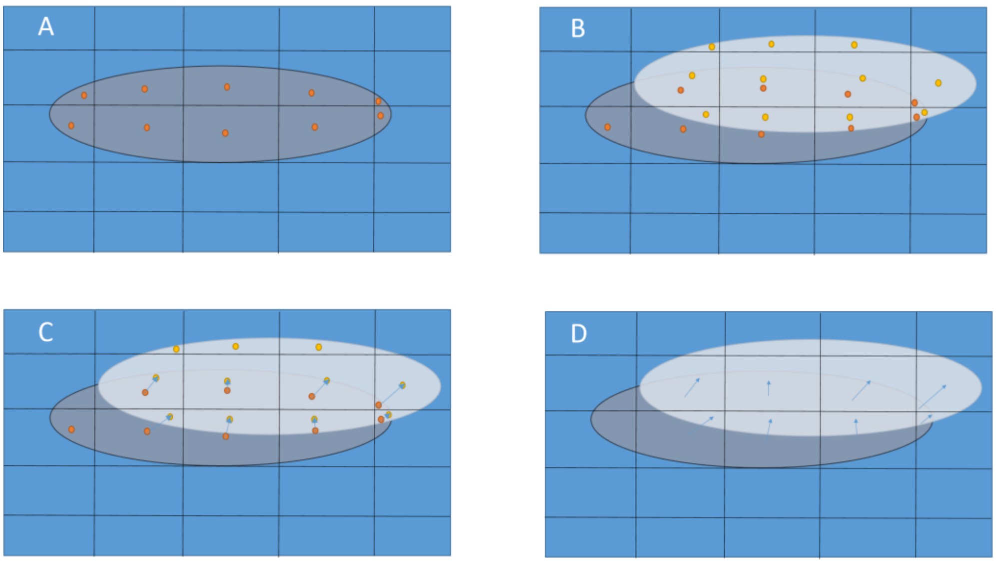

Figure 6: Visualization of the movement detection method. A) The average X and Y are visualized as the coordinates for the representative points of the corresponding point. B) the average X and Y are calculated for two following years. C) The vectors have been drawn between these two points. D) The isolated movement vectors of two following years.

grid at the locations of the sandbars. For each cell of the raster the average of the X coordinates and the Y coordinates will be taken resulting in a point. This point represents the location of a sandbar in a cell. The Euclidian distance between these point in one cell is the travelled distance of the sandbar in this cell. What will result is a map similar to those used in wind- speed and direction maps.

The cell size and the grid size have a major influence on the resulting movement. For this research there has been chosen for a ratio of 1:4, a cell size of the height of an area divided by 20 and a grid size of the height of an area divided by 80. The sizes are dependent on the size of the area so that there are an even number of cells per area. There are 16 points in each cell. It is assumed that these were enough points to give a good representation of the sandbars in this cell. More research is needed to explore the error propagation in relation to the grid and cell sizes.

A possible error is that a sandbar could be recognized in the bottom of a cell where it just migrated into. In this same cell a sandbar from the previous year could have just migrated out. This would result in a movement in the wrong direction. To correct for this the maximum movement in the X direction has been set to half the cell size and the maximum movement in the Y direction has been set to a quarter of the cell size. This difference is present because the long shore movement of sandbars is smaller than the cross shore movement (Albuquerque et al. 2011).

4.4 RQ2 Comparison of characteristics

4.4.1 RQ 2.1 How does the volume of sandbars change in space

The volume of sandbars is compared between coastal areas. The comparisons of the means of the fifteen coastal areas and the three coastal regions were done using one- way ANOVA. The significance level (α) that is used is 0.05. To robustly one-way ANOVA three assumptions have to be satisfied (Scariano & Davenport 1984). The population must be normal, the observations have to be independent from each other and the samples must have equal variance.

The equal variance will be tested using the Shapiro-Wilk test with a significance level of 0.05. The samples were assumed to be independent since the samples were taken from separate coastal areas and therefore do not influence each other. The equal variance will be tested using Levene's test with a significance of 0.05. When two samples that are compared both satisfy all the necessary assumptions the difference between the means will be calculated. The null hypothesis that will be tested states that the mean of the volume in the first coastal area is equal to the mean of the volume in the second coastal area (see Eq. 4), the alternative hypothesis states that the mean of the first group is not equal to the mean of the second group (Eq. 5).

Eq. 4 $$H_0: \mu_1 = \mu_2$$
Eq. 5 $$H_1: \mu_1 \neq \mu_2$$

4.4.2 RQ 2.2 How does the shape of sandbars change in space

The shape of sandbars will be compared between coastal areas. The comparisons of the means of the fifteen coastal areas and three coastal regions will be done in the same manner as for the volume, the method is described on page 15.

4.4.3 RQ 2.3 How does the movement of sandbars vary over space

The difference in mean movement in the U and V direction, respectively long- and cross shore movement will be calculated using the same procedure as for section 4.4 and 4.4.2 is used. The method is described on page 15.

5 Results

In this chapter the results of the proposed methodology are presented. Firstly the detected sandbars and the methods to do so are presented in section 5.1. Two important steps are highlighted: The transformation of the points and the comparison of the interpolation techniques in sections 5.1.1.1 and 5.1.1.2. The overall results of the sandbar detection are presented in section **Error! Reference source not found.**. The results of the characterization are presented in 5.1.2 The results of the comparisons of the characteristics are presented in section 5.1.2.

5.1 RQ1 Detection of sandbars

5.1.1 RQ 1.1: Detection of sandbars

5.1.1.1 Transformation of the points

In Figure 9 an example of the transformation is given. The red highlighted locations are the locations where the depth was zero NAP. After the transformation it is visible that the zero-depth points lie on a straight line. The area of the white points is analysed to find the sandbars.

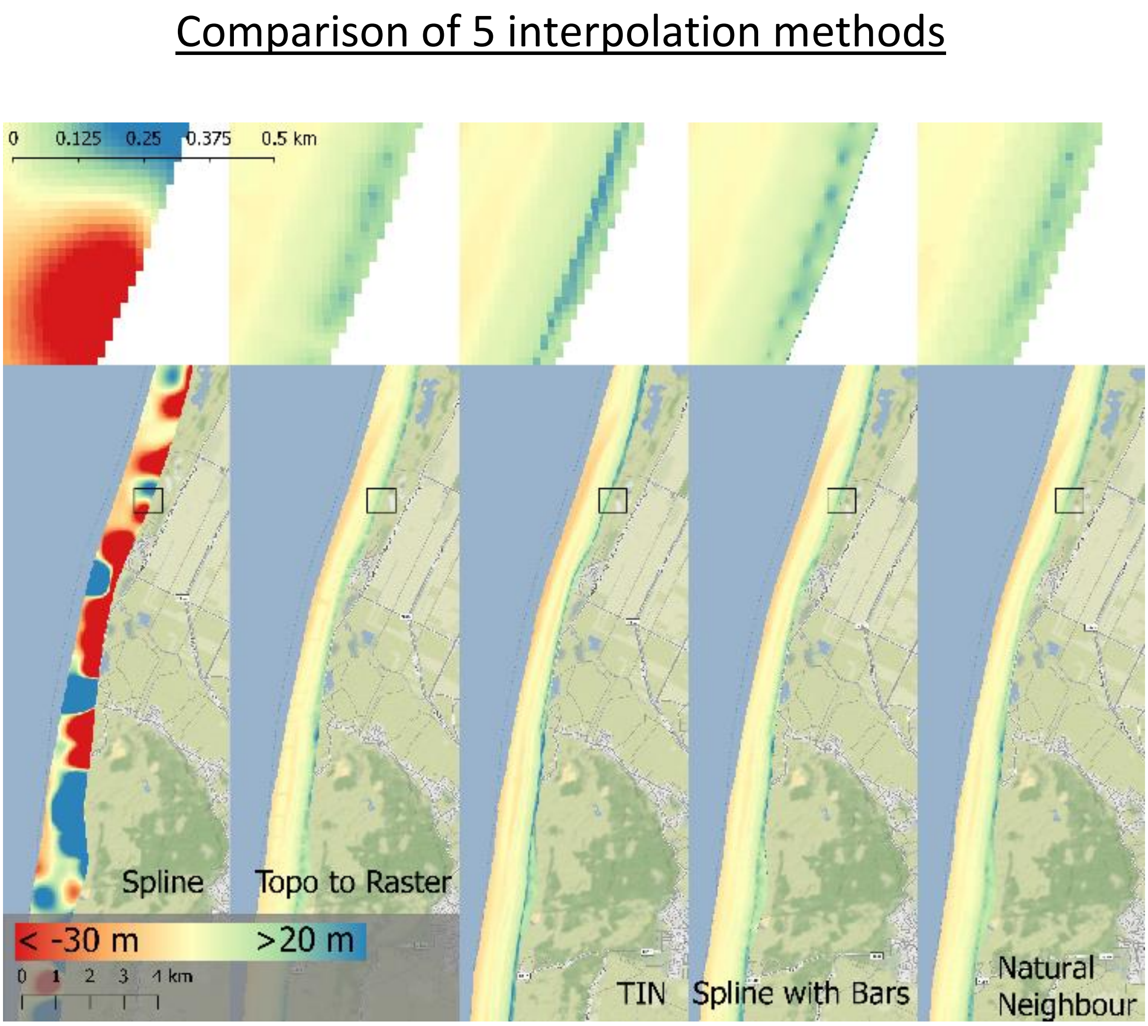

Figure 8: Five interpolation methods of the coastal area Noord-Holland in 2008. 5 compared techniques: Spline, Topo to Raster, Delaunay triangulation, Spline with Bars and Natural Neighbours. At the top of each larger image an enlargement of an area indicated by a rectangle is shown.

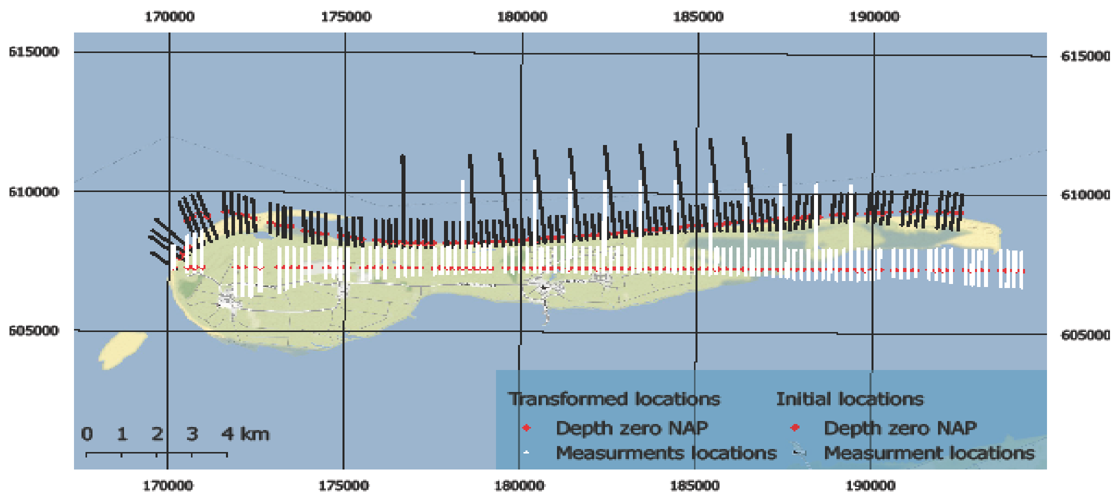

Figure 9: Measurement locations of Ameland in 1965. Visualization of the original measurement locations (in black) and the transformed location (in white). In both sets of points the location where the depth is zero is highlighted in red.

5.1.1.2 Comparison of interpolation techniques

Five interpolation methods where compared: ArcMap's *Spline*, *topo to Raster*, *Delaunay triangulation*, *spline* with Bars and *natural neighbour interpolation*. The results were visualized in Figure 8. The *spline* method results in a dynamic bathymetry. Depths range from less than -100 meter to more than 90 meter. There is no visible dune range and no visible elongated features. The *Topo to Raster* tool results in a smooth bathymetry where elongated features are visible. The slope of the bathymetry is seaward and long, cross shore trenches are visible. At the coast a dune range is visible which is irregularly indented. The *Delaunay triangulation* results in a smooth bathymetry with a clear long stretched dune range. In the sea there are long shore elongated shapes recognizable. The result of the *spline with bars* method resembles the result of the *Topo to Raster* tool. Also trenches perpendicular on the coast are visible although they are less clear than in the *Topo to raster* result. Additionally, the dune range is indented every 200 meter similar to the *Topo to Raster* tool. The *natural neighbour interpolation* method results in a smooth bathymetry. Although less than in the *Topo to Raster* and Spline, trenches are visible. The indented dune range is present that was visible at the *topo to raster* and *spline with bars.*

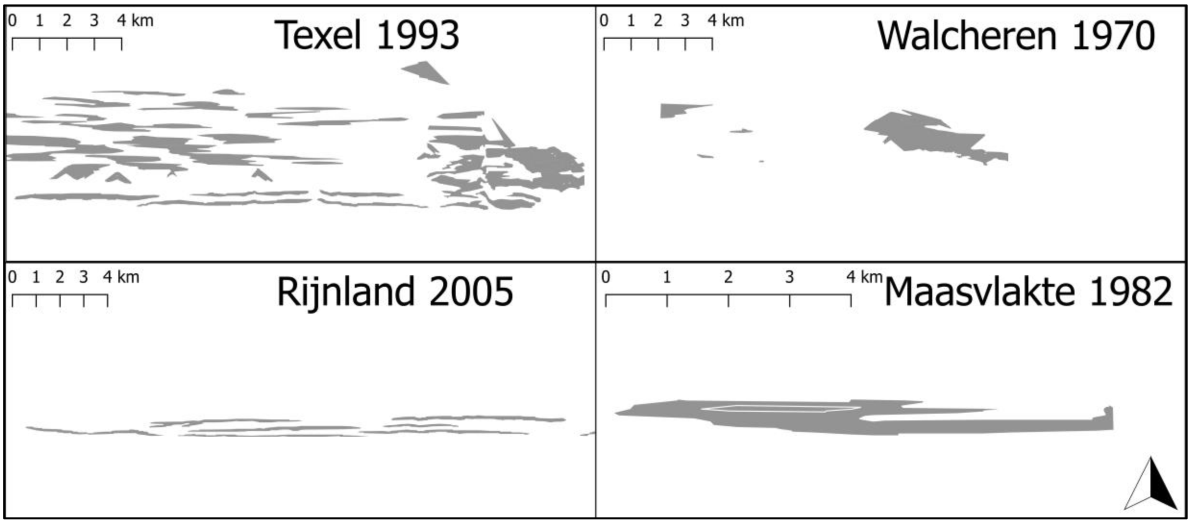

Figure 10: Four examples of detected sandbars. The sandbars close to Texel 1993 (Island region) show triangulate artefacts. The sandbars found close to Walcheren 1970 (Zeeland region) show an uncommon shape. Rijnland 2005 (Noord Holland region) shows long stretched sandbars. Maasvlakte 1982 (Zeeland region) shows one relatively small sandbar and another smaller one that overlaps with the larger sandbar.

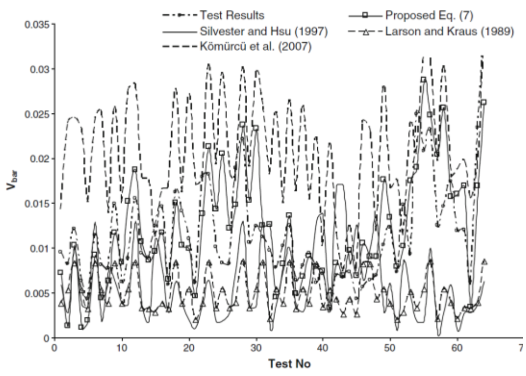

Figure 12: Image from Demirci et al. It contains results from several formulas that calculate the volume of sandbars. The volume ranges from approximately zero to 0.35.

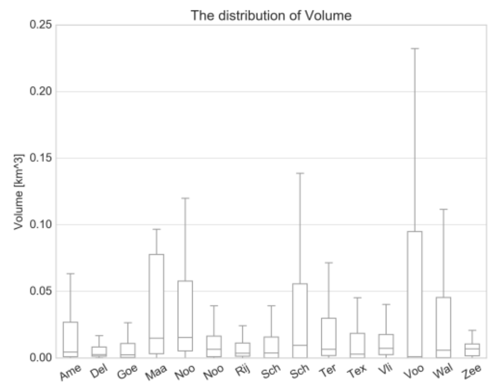

Figure 11: The distribution of the volumes of the sandbars from this thesis research. All years are displayed. The outliers have been removed. For visualization purposes.

5.1.1.3 Sandbar Recognition

In total 4822 sandbars have been detected. Figure 10 shows four examples of sandbars in coastal areas. The most convenient way to visualize sandbars is to show them in context with their respective coast. After transformation of the sandbars this is not possible, since no transformed coast exists. In this paper the east west direction is cross shore and the north south direction is long shore. In Texel 1993 many sandbars are found with many different shapes. The most remarkable shapes are the triangulate shapes. Also remarkable is the amount of sandbars that are detected. The sandbars from Rijnland 2005 are long-stretched. This was common along long stretches of coast and at the long sides of islands. Maasvlakte in 1982 shows one small sandbar relative to the other sandbars that are shown. On this sandbar another, smaller, sandbar is detected.

5.1.2 RQ 1.2: Characterization of sandbars

5.1.2.1 Volume

The average volume is 0.033 cubic kilometres and the standard deviation is 0.099. The minimum volume is 54.700 cubic meter and

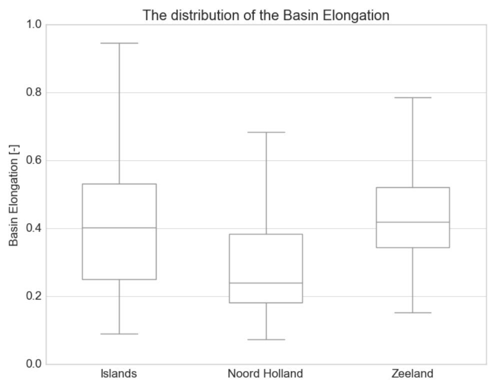

Figure 13: The distribution of the basin elongation for the three coastal regions. In the image outliers have been removed for visualization purposes.

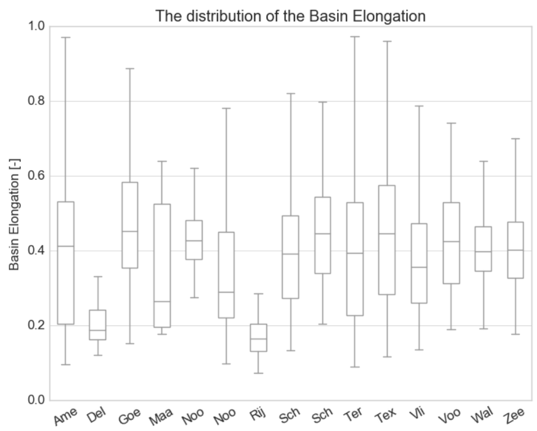

Figure 14`: The distribution of the basin elongation for the fifteen coastal areas. In the image outliers have been removed for visualization purposes.

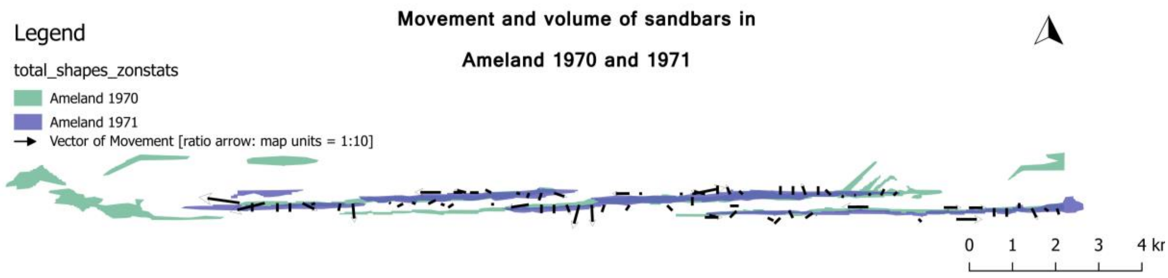

Figure 16: Example of detected movement of sandbars is depicted by the black arrows. In correspondent coloured text the volume per sandbar in cubic kilometres is depicted for each separate sandbar. De length of a vector of movement is ten map units.

the maximum is 0.96 cubic kilometre. Many sandbars are found with a higher volume than the largest sandbar found by Demirci et al. (2014), however most of the volumes are in the same order of magnitude., as is shown in Figure 11. When visually compared the volumes seem slightly lower. However this is not statistically confirmed.

5.1.2.2 Shape

In Figure 13 the distribution of the basin elongation is visualized for the fifteen coastal areas. Figure 13 shows the distribution of the basin elongation in the three coastal regions. The total mean is 0.39 and the standard deviation is 0.17. The minimum is 0.074 and the maximum is 1.59. Figure 15 shows an example of some sandbars close to Texel in 2001. It shows an example of a basin elongation larger than one. A basin elongation of one indicates a perfect circle according to Schumm (1956). However, this statement is based on the assumption that basins, for which this parameter was developed, have regular shapes without inlets. Sandbars have irregular shapes for example, horseshoe shapes. These shapes explain the values above 1.

5.1.2.3 Movement

An example of the movement within an coastal area is shown in Figure 16. A visual inspection shows a movement of the sandbars in the mid left of the image towards the land where in the mid right the movement is more seaward.

The average movement per coastal area and per coastal region in the U and V, respectively in the long- and cross shore, direction where calculated as is visible in

Figure 18 and Figure 17.

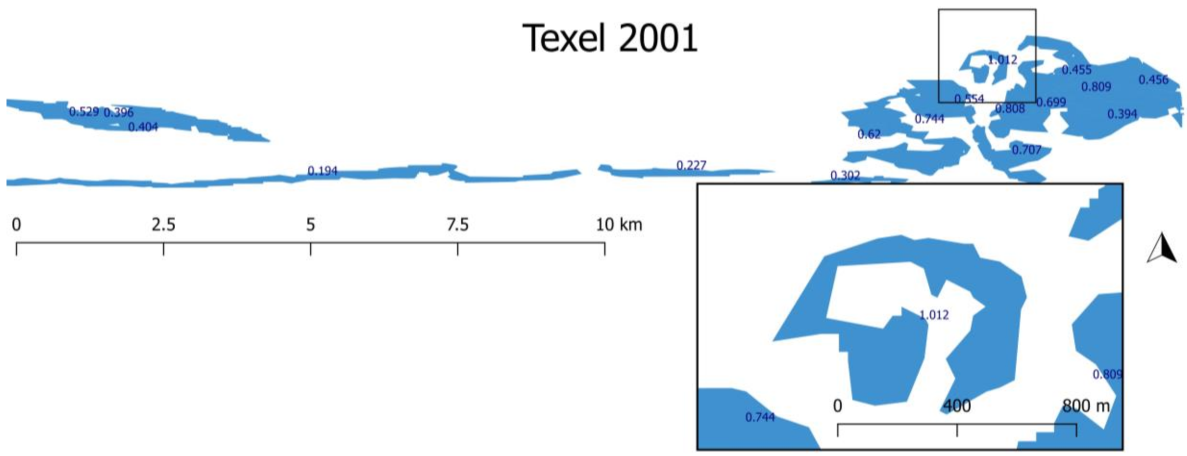

Figure 15: A selection of sandbars close to Texel 2001. The darker text close to each island is the basin elongation. A sandbar with a basin elongation above one have been enlarged.

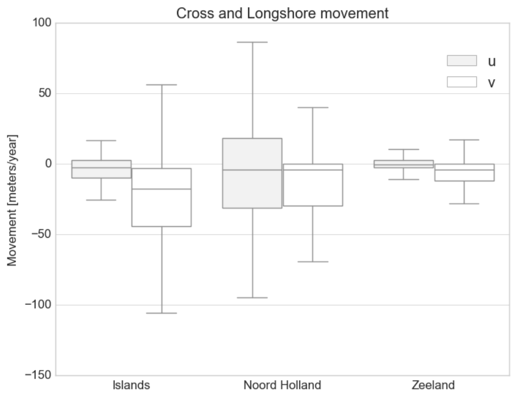

Figure 17: Boxplot of the cross and longshore movement in the coastal regions. The outliers have been removed.

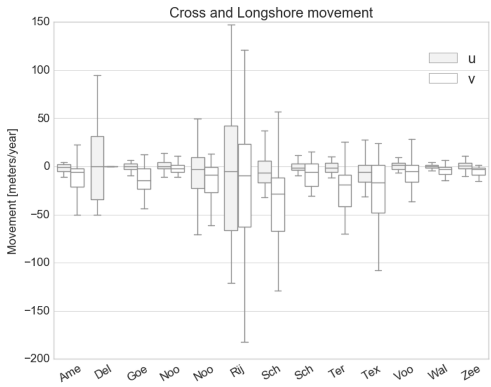

Figure 18: Boxplot of the cross and longshore movement in the coastal areas. The outliers have been removed. For visualization purposes.

5.2 RQ 2 Comparison of characteristics

5.2.1 Volume

Approximately half of the volume values lies between 0.01 and 0 cubic kilometres, the other half ranges from 0.01 to one cubic kilometres, causing the residuals to be not normally distributed. To correct for this the logarithm of the volumes is analysed instead of the volume. In Figure 19 the distribution of the logarithm of the calculated volumes in this research is displayed per coastal area. The logarithm is analysed because distribution is not normal for the volumes.

Table 2 shows the analysis of variance (ANOVA) between all the separate coastal areas where the two remaining assumptions are satisfied. The bold numbers indicate that the p-value is below 0.05. Maasvlakte and Delfland did not have normally distributed residuals. The other p-values that are missing in the table did not satisfy the assumption of unequally distributed variances.

Figure 19 shows the distribution of the logarithm of the volume per coastal region, which are the same values as in the coastal regions but clustered which makes it possible to compare bigger groups.

5.2.2 Shape

In Table 3 the p-values for the differences in means are given from the one-way ANOVA test. The null hypothesis is that there is no significant difference between the means of the two compared coastal areas with a significance level of 0.05. The values in bold are lower than the significance level. In Table 4 the p-values are given for the differences in means tested with a one-way ANOVA. The null hypothesis is that there is no difference between the means of the different coastal regions.

5.2.3 Movement

The means are compared using the one-way ANOVA. As is mentioned on page 15 three assumptions have to be satisfied in order to perform the test. The long shore direction did not result in any test values since the variances are not equal within the groups. The cross shore direction comparisons between the coastal areas are summarized in Table 6. The cross shore movement comparisons between the coastal regions are summarized in Table 7. One value could be calculated, the other groups did not have equal variances.

de Vroeg (1987) found a difference in cross shore migration velocity between the north and the south of the Netherlands. He found a cross shore migration of 10 to 20 meter per year in the north and a velocity of 50 meter per year in the south. His results are shown in Table 1. The average movement he found is 29.33 meter per year. In the North Holland region an average cross shore movement was found of –22.51 meter per year with a standard deviation of 73.00 meter per year The Shapiro Wilk test results in a P-value of 0.31 for the speeds found by de Vroeg. The cross shore movements in same region in the same period results from this study results in a P-value of 0.017. The Levene's test gave a P-value of 0.16. Keeping this in mind, the one-way ANOVA results in a P-value of 0.343.

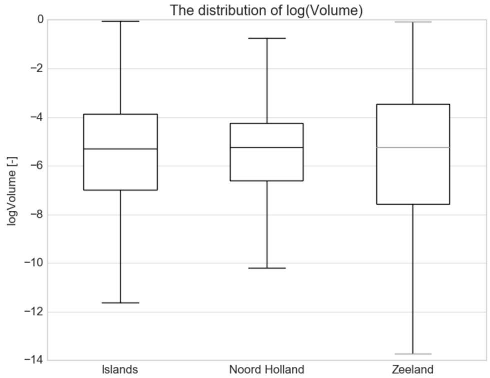

Figure 19: Boxplots of the logarithm of the volume per coastal region. In the image outliers have been removed for visualization purposes.

Table 1: Table of the migration speeds found by de Vroeg (1987). The studied area is the are known in this research as Noord Holland. He studied the coast based on Jarkus data with a interval between the transects of 5 km. The studied period was from 1970 to 1984

Tabel 3.1
Enkele eigenschappen brandingsruggen,
geschat UIT 3-D-TIJD WEERGAVEN

raainr.	L (m)	C (m/jaar)	Per (jaar)
9.94	400	vrijwel 0	zeer groot
20.15	400	vrijwel 0	zeer groot
30.00	300	20	15
40.00	300	16	19
50.00	350	13	27
IJmuiden			
60.00	200	70	3
70.00	240	50	5
80.00	200	50	4
90.00	240	45	5
101.00	-	-	-
109.96	-	-	-
116.62	-	-	-

- = geen duidelijke brandingsruggen in profiel

Table 2: Table containing the P-values of the differences between the volumes of the fifteen coastal areas that satisfy the assumptions for doing an ANOVA. The null hypothesis of this test is that the difference between the volumes are equal within the coastal areas. The values that are in bold are lower than 0.05, which indicate a significant difference with 95% certainty. The dark grey squares are the islands that did not have normally distributed residuals.

	Ame	Del	Goe	Maa	Noo	Noo	Rij	Sch	Sch	Ter	Tex	Vli	Voo	Wal	Zee
Ameland	1														
Delfland		1													
Goeree	**0.006**		1												
Maasvlakte				1											
NoordBeveland					1										
NoordHolland						1									
Rijnland							1								
Schiermonnikoog								1							
Schouwen									1						
Terschelling	**0.003**		**2.65E-08**			**3.48E-4**				1					
Texel								0.304			1				
Vlieland					**8.23E-4**							1			
Voorne													1		
Walcheren								**2.51E-05**	0.455		**4.31E-4**			1	
ZeeuwsVlaanderen					**2.85E-07**							**0.006**			1

Table 3: Table containing the P-values of the differences between the basin elongation of the fifteen coastal area that satisfy the assumptions for doing an ANOVA. The null hypothesis of this test is that the difference between the mean basin elongations are equal within the coastal areas. The values that are in bold are lower than 0.05, which is the significance level.

	Ame	*Del*	*Goe*	*Maa*	*Noo*	*Noo*	*Rij*	*Sch*	*Sch*	*Ter*	*Tex*	*Vli*	*Voo*	*Wal*	*Zee*
Ameland	1														
Delfland	***6.14E-15***	1													
Goeree		***9.27E-36***	1												
Maasvlakte				1											
NoordBeveland					1										
NoordHolland	***2.20E-05***	***3.11E-08***				1									
Rijnland					***3.51E-69***		1								
Schiermonnikoog		***4.16E-22***						1							
Schouwen	0.079	***2.31E-16***				***3.30E-07***		0.890	1						
Terschelling	***3.99E-4***	***3.34E-21***				***1.38E-15***			0.278	1					
Texel										0.992	1				
Vlieland		***2.80E-28***	***0.015***					***0.022***	0.109			1			
Voorne	***4.91E-08***	***2.36E-24***				***1.03E-17***		***1.93E-05***	***6.99E-4***	***0.006***	***0.005***		1		
Walcheren		***4.57E-14***	***3.44E-10***					***0.024***	0.054			***2.26E-05***		1	
ZeeuwsVlaanderen			***1.85E-4***		***0.003***									0.074	1

Table 4: Table containing the P-values of the differences between the basin elongation of the coastal groups that satisfy the assumptions for doing an ANOVA. The null hypothesis of this test is that the difference between the mean basin elongations are equal within the coastal regions. The values that are in bold are lower than 0.05, which is the significance level.

	Isl	*Noo*	*Zee*
Islands	1		
Noord Holland	***7.34E-16***	1	
Zeeland			1

Table 5: P-values of the difference between the mean values of the long shore (u) movement-profile under the null hypothesis: the movement is equal in the groups of coastal areas under a significance of 0.05. Only the P-values are shown where the assumptions are satisfied.

	Ame	*Del*	*Goe*	*Maa*	*Noo*	*Noo*	*Rij*	*Sch*	*Sch*	*Ter*	*Tex*	*Vli*	*Voo*	*Wal*	*Zee*
Ameland	1														
Delfland		1													
Goeree	0.592		1												
Maasvlakte				1											
NoordBeveland	0.620		0.993		1										
NoordHolland						1									
Rijnland		0.974					1								
Schiermonnikoog	0.406							1							
Schouwen	0.378		0.533		0.558				1						
Terschelling										1					
Texel								0.658			1				
Vlieland												1			
Voorne	0.832		0.243		0.281				0.094				1		
Walcheren	0.591													1	
ZeeuwsVlaanderen															1

Table 6: P- values of differences between the mean values of the cross shore (v) movement-profile under the null hypothesis: the movement is equal in the coastal areas in under a significance of 0.05. Only the P-values are shown where the assumptions are satisfied.

	Ame	*Del*	*Goe*	*Maa*	*Noo*	*Noo*	*Rij*	*Sch*	*Sch*	*Ter*	*Tex*	*Vli*	*Voo*	*Wal*	*Zee*
Ameland	1														
Delfland	0.958	1													
Goeree	0.357	0.653	1												
Maasvlakte				1											
NoordBeveland		0.193			1										
NoordHolland	0.322	0.558	0.721			1									
Rijnland							1								
Schiermonnikoog								1							
Schouwen	0.713	0.874	0.645			0.473			1						
Terschelling		0.163	0.112			0.317			***0.048***	1					
Texel		0.495				0.670	0.958			0.765	1				
Vlieland												1			
Voorne	0.479	0.666	0.167			0.170			0.355	***0.009***			1		
Walcheren		0.261			0.110									1	
ZeeuwsVlaanderen		0.312			***0.028***									0.466	1

Table 7: P-values of the difference between the mean values of the cross shore (v) movement-profile under the null hypothesis: the movement is equal in the groups of coastal regions under a significance of 0.05. Only the P-values are shown where the three assumptions are satisfied.

	Noo	*Zee*	*Isl*
Noord Holland	1		
Zeeland		1	
Islands	0.588		1

6 Discussion

In this section the results that are presented in the previous section will be discussed and possible side notes will be given. In section 6.1 the detection of the sandbars will be discussed, the step where interpolation techniques are compared will receive some extra attention. In section 6.2 both the method for characterization as the comparison of the sandbars will be discussed starting with the volume followed by the shape and the movement.

6.1 RQ1.1 Detection of sandbars

The recognition of the sandbars was successful. The long-stretched shape of the sandbars at the longer stretches of straight coast seem to resemble the established conclusions of sandbar shape. Some unexpected shapes were detected, especially in the smaller, curved coastal areas. Here the recognition process seems to perform unexpected.

The raw JARKUS data contains measurements on the same location with a different depth. The latter of these has been included in the point data. There has been no comparison or statistical evaluation about the truth of this method.

During the transformation of the points the transect lines have been transformed so that the zero-depth points lie on a straight line. The assumption that was made is that the first zero-depth points together formed a continuous coast line. This

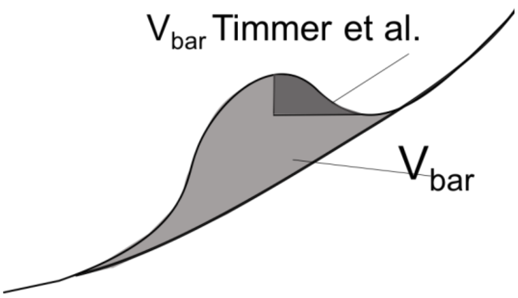

Figure 20: The part of the sea bed profile that is detected as sandbar volume by the method proposed by the author. The black line is the sea bed profile and the grey area is the area that is detected as being volume of the sandbar.

assumption is false, since there are little pools present on the beach that contain measurements below zero. These zero-depth points that lie more land inwards than most of the zero-depth points cause to transects to shift. These shifted transects cause artefacts for which is not compensated. This causes triangulate shapes as seen in the top left image of Figure 10. One transect is moved northwards because the origin of this transect is taken as the first zero-depth point that is found. As a result, the entire transect is shifted causing a possible sandbar to contain triangulate shapes.

The use of the aspect to identify the location of sandbars has to be further studied. The part of a sandbar that is detected is the part that faces the coast. A sandbar however is a symmetrical feature that does not contain only coastal facing slopes as is shown in Figure 20, it has a second side with a slope facing sea wards. About half of the sandbar, the slope facing to the coast, has been identified using the proposed method. This resulted in a systematic estimation error in the calculation of the volume of sandbars and has consequences for the shape as will be elaborated on in sections 6.2.1 and 6.2.2. For comparisons using the same identification method this showed complications.

The aspect has been calculated using ArcMap's aspect tool, however no other methods have been tested. For the Jenks optimization method also no other methods have been compared.

6.1.1 Comparison of interpolation techniques

The interpolation techniques are compared visually, not statistically, because of time constraints, they could be compared more in depth using quantitative techniques like cross referencing.

The *spline* tool showed a pattern which does not show any similarity with the bathymetries that are found in literature. The *topo to raster*, *spline with bars* and *natural neighbour* methods all showed perpendicular trenches at the locations of the transects. These are considered to be artefacts caused by a faulty interpolation and would cause serious errors in volume, shape and movement. A selection criterion was set to the dune range. A continuous elevation along the coast was expected as is present in a dune range in reality. At the *spline*, *topo to raster*, *spline with bars* and *natural neighbour* this continuous line was interrupted at the same frequency as the perpendicular trenches which is not seen in literature. Although based on assumptions and visual comparison rather than on hard facts, the *Delaunay triangulation* was chosen to be used in this study since it showed the smoothest surface resembling the reality the best.

6.2 RQ1.2 Characterization of sandbars

6.2.1 Volume

Not only the top of the sandbar is variable in height, also the base of the sandbar is variable in height within a sandbar resulting in a theoretical underestimation of the volume in this research. The method for detecting sandbars that is used in this research influences the shape and therefor comparisons with other studies as well as within this study showed complications as will be elaborated on later this section. In Figure 20 an example of detected sandbar volume is visualized. In Figure 11 distribution of volumes in coastal areas is visualized in boxplots. The results of Demirci, Aköz, and Üneş (2014) range from 0 to 0.35 cubic kilometres, the volumes found in this research range from 5.4E-5 to 0.96 cubic kilometres. As is shown in Figure 20, in the method used in this study the base of a sandbar is horizontally rather than diagonally and sandbars are only partially detected. This causes the volume to be systematically underestimated. The values that are found range to almost three times the maximum value found by Demirci, Aköz, and Üneş (2014). Figure 11 shows the distribution of the volumes that is found. The values that exceed the maximum values found by Demirci, Aköz, and Üneş (2014) are outliers. The majority of the values that are found seem slightly lower than the values found by Demirci, Aköz, and Üneş (2014).

In the comparisons that did satisfy the assumptions needed for doing a one-way ANOVA, the P-values show that the majority of the means of the volumes within coastal areas are unequal, see Table 2. The assumptions that have to be satisfied to do the one-way ANOVA showed a large amount of combinations of coastal areas and regions where the variances are not equally distributed. This is due to the underestimation mentioned in the beginning of this section, the variance within the coastal areas becomes bigger. The top of a sandbar is easier to detect than the base of a sandbar. Demirci, Aköz, and Üneş (2014) use a straight diagonal line from the height of the land to the lowest point as a base for sandbars. In an artificial environment, like in the wave tank that is used, this is possible. Due to compilations in defining the diagonal line in reality this is not so easy. The base of a sandbar has a large influence on the volume that is calculated. The varying slopes in this research account for different degrees of under estimations that result in unequal variances. The variances are significantly different and therefor the assumptions that are expected by the ANOVA are not satisfied. This causes a large variance within the coastal areas suggesting that the one-way ANOVA is not the best test to compare the different coastal areas.

In two coastal areas the residuals are not equally distributed, Maasvlakte and Delfland. Maasvlakte is a small coastal area containing many curves and other irregularities. Delfland is an area where there is constant altering of the shoreline due to the construction of a big coastal protection feature called the 'Zandmotor'. This may have caused the residuals to be unequally distributed although this has not been studied.

6.2.2 Shape

As is shown in Figure 14 the mean values of the basin elongation range from about 0.20 to 0.45. This means that sandbars are more elongated than round. This corresponds to visual observations from findings of de Vroeg (1987) and Exon (1975). Visual observations of

Figure 10, and Figure 16 show that there is a spatial pattern of the shapes within coastal areas in the islands region. Around the islands the sides of the area contain smaller rounder islands than in the middle. Since there was no comparison of shapes within a coastal area no conclusions can be drawn but it implies that the average of the basin elongation of an entire coastal area is not a proper statistic to show all the variation along the coast.

Similarly to the volume, many of the comparisons of the means where not possible due to unequal variances. This could mean that the sample size was too small. This is likely since especially the smaller coastal areas can contain a small number of sandbars per year. However during the comparison between the coastal regions, the sample sizes are larger and still mostly the variances are unequal, implying that the problem is not the sample size.

Among the regions there was one comparison of means, the Islands and Noord Holland. These showed to be significantly different.

6.2.3 Movement

Most of the movements per coastal area are in the negative direction, both for the long and cross shore direction. This means that the general movement is to the south west in the transformed images. The movement in the long shore direction is smaller than the movement in the cross shore direction. This can have several reasons. The movements are averaged over an coastal area while there is large spatial variation of movement within these areas as is found on page 28. The movements are also averaged over time while literature suggest cyclic behaviour of sandbars (Ruessink & Kroon 1994; Wijnberg & Kroon 2002).

Averaged movement over the coastal area means that the movement of large sandbars is detected at more locations than movement of smaller sandbars since movement of larger sandbars will be found in more cells, the movement of larger sandbars weighs heavier than the movements of smaller sandbars. This causes the larger sandbars to be represented more than smaller sandbars.

de Vroeg found migration speeds of 10 to 50 meter per year in the area from 'De Hoek van Holland' until 'Den Helder', which is the region called Noord Holland in this research. Figure 17 shows the movements found in this research. This is the same order of magnitude as the majority of the movement speeds found in this research, although higher values are found. Based on the P-value of 0.343 resulting from the ANOVA test, the null hypothesis is not rejected. A side note has to be made that the three assumptions are not satisfied. The sample size of the results found by de Vroeg was too small and the residuals where not equally distributed.

7 Conclusions

Based on the results and the discussion of these some conclusions can be drawn. In this section they are concretely enumerated.

7.1 How to detect and characterize near shore sandbars in the JARKUS dataset using GIS techniques?

7.1.1 How to detect near shore sandbars with the use of the JARKUS dataset?

To detect near shore sandbars, series of data manipulations have been done. Firstly, the data is converted to points. These spoints are transformed so that they run parallel, perpendicular to the coast. These transformed points are interpolated using Delaunay triangulation. Of the resulting DEM the aspect is calculated. The areas facing the shore with the restrictions given by the definition are defined as sandbars.

7.1.2 How to characterize the volume, shape and movement of near shore sandbars?

For characterization of sandbars three parameters are calculated: volume, shape and movement. The volume is calculated by summing the area above the lowest point that is found in a sandbar. The shape is quantified by the basin elongation which is the longest line in a polygon divided by the diameter of a circle with the same area as the polygon. The movement is quantified in the long shore and cross shore direction by dividing an area into cells. Within these cells the average location of sandbars is calculated as a point. The difference in the long and cross shore direction in two following years is the movement in this cell. The average of these movements is taken as the average movement of this area.

7.2 How do the recognized characteristics vary in the defined coastal areas and regions along the Dutch coast?

7.2.1 Does the volume of near shore sandbars vary in the defined coastal areas and regions along the Dutch coast?

A relatively small amount of statistical comparisons of the volume within the coastal areas could be done because of untrue assumptions. The comparisons that could be made show that there is a significant difference between the volumes in most of the coastal areas.

7.2.2 Does the shape of near shore sandbars vary in the defined coastal areas and regions along the Dutch coast?

To do the one-way ANOVA assumptions have to be satisfied In the coastal areas where the assumptions that are needed are satisfied show a significant difference between the shapes of sandbars between the coastal areas. The shapes of sandbars at the Islands are significantly different than the shapes of sandbars in the Noord Holland region. In general one could say that there is a variety of sandbar shapes among the Dutch coast.

7.2.3 How do long- and cross shore movement of near shore sandbars vary in the defined coastal areas and regions along the Dutch coast?

No significant differences have been found in the long shore movements between the coastal areas. The coastal regions could not be statistically examined because of false assumptions for the statistical test. The cross shore movement shows some significant differences between coastal areas but the regions do not. Again the majority of the statistical tests could not be done due to untrue assumptions or the statistical test.

8 Recommendations

Based on the experience gained by this research and the discussion and conclusion of the results some recommendations can be done.

The method which is proposed for the detection of sandbars is not validated. Therefor no conclusions can be done about the accuracy of this method. This validation should be done. Found sandbars should be compared to field observations. The outcome of the validation can be used to detect outliers and faulty detected sandbars. The same counts for the characteristics. The volume and movement are compared to literature. However comparison should be done with a control group. Both the proposed methods as the methods they are compared to should be calculated over the same data. In this way objective results can be statistically compared.

Delaunay triangulation is used as the best interpolation technique. It is compared to other deterministic interpolation techniques however stochastic interpolation techniques should be taken in consideration as well.

The movement has been averaged over time, neglecting the possible cyclic behaviour as is found in previous literature (Ruessink & Kroon 1994; Aleman et al. 2013). The cyclic behaviour should be studied on a large spatial scale. By not using an average movement over time, also behaviour of sandbars in response to changes in climate or human intervention can be studied as well as changes in movement of sandbars in general.

All the characteristics have been averaged over space neglecting the spatial patterns that were found by visual observations. These spatial patterns should be studied and compared on a large temporal and spatial scale.

The clustering of the coastal areas in coastal regions has been done based on obvious coastal characteristics. More attention has to be paid on this division. In specific, what are coastal characteristics that define coastal regions and influence sandbars and how do they differ from each other.

For further research on how volume changes in sandbars, another method for volume calculation should be used. Although the results are comparable with volumes in literature, the theoretical under estimation should not be neglected.

The basin elongation was used as a proper parameter for sandbar shape. This parameter should be compared to other parameters. Apart from studying sandbar shape in two dimensions among coastal areas and regions, more attention has to be paid to the difference within sandbars. Also the third dimension can be introduced by studying the base of the sandbars and the shape of the top of the sandbars.

The one-way ANOVA was used to compare the volume, shape and movement of sandbars. However the assumptions that need to be satisfied to use this test were often not satisfied. Other tests should be used. Attention has to be paid so that there is no assumption for equally distributed variances. Parametric tests should be considered.

After validation and cleaning of the data, the sandbars that can be found using the proposed method can be used as a trainings dataset for supervised classification methods and possibly self-learning methods such as neural networks. These methods could decrease the computing time and possibly the accuracy of detection.

9 Bibliography

Aagaard, T., 2013. Sediment Transport. In *Treatise on Geomorphology*. pp. 74–105.

Albuquerque, M.G. et al., 2011. Beach morphodynamics and characterization of sand bars in mesotidal environments. *Journal of Coastal Research*, (64), pp.2012–2016.

Aleman, N. et al., 2013. Net offshore bar migration variability at a regional scale: Inter-site comparison (Languedoc-Roussillon, France). *Journal of Coastal Research*, 165(January 2013), pp.1715–1720. Available at: http://www.bioone.org/doi/10.2112/SI65-290.1.

Aleman, N. et al., 2011. Typology of nearshore bars in the Gulf of Lions (France) using LIDAR technology. *Journal of Coastal Research*, (SI64), pp.721–725.

Bárdossy, A. & Schmidt, F., 2002. GIS approach to scale issues of perimeter-based shape indices for drainage basins. *Hydrological Sciences Journal*, 47(6), pp.931–942.

Cambazoglu, M.K., 2009. Numerical modeling of cross-shore sediment transport and sandbar migration. , (December), p.222.

Carter, R.W.G. & Balsillie, R.H., 1983. A note on the amount of wave energy transmitted over nearshore sand bars. *Earth Surface Processes and landforms*, 8, pp.213–222.

Chen, J. et al., 2013. Research on geographical environment unit division based on the method of natural breaks (Jenks). *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, 40(4W3), pp.47–50.

Cignoni, P., Montani, C. & Scopigno, R., 1998. DeWall: A fast divide and conquer Delaunay triangulation algorithm in Ed. *Computer-Aided Design*, 30(5), pp.333–341. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0010448597000821.

Damsma, T., 2009. Dune growth on natural and nourished beaches: “A new perspective.” , (April).

Davidson-Arnott, R.G.B., 2013. Nearshore Bars. In *Treatise on Geomorphology*. pp. 131–145.

Dean, R.G., 1991. Equilibrium Beach Profiles : Characteristics and Applications. *Journal of Coastal Research*, 7(1), pp.53–84.

Demirci, M., Aköz, M.S. & Üneş, F., 2014. Experimental investigation of cross-shore sandbar volumes. *Journal of Coastal Conservation*, 18(1), pp.11–16.

Elgar, S., Gallagher, E.L. & Guza, R.T., 2001. Nearshore sandbar migration. *Journal of Geophysical Research*, 106(C6), p.11623.

ESRI, How Aspect Works. Available at: http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/how-aspect-works.htm [Accessed January 1, 2017a].

ESRI, How Natural Neighbour Works.

ESRI, How spline with barriers works. Available at: http://edndoc.esri.com/arcobjects/9.2/net/shared/geoprocessing/spatial_analyst_tools/how_spline_with_barriers_works.htm [Accessed November 2, 2017c].

ESRI, How Topo to Raster works. Available at: http://pro.arcgis.com/en/pro-app/tool-reference/3d-analyst/how-topo-to-raster-works.htm [Accessed January 1, 2017d].

Exon, N.F., 1975. An extensive offshore sand bar field in the western baltic sea. *Marine Geology*, 18, pp.197–212.

Guillén, J. & Hoekstra, P., 1996. The “equilibrium” distribution of grain size fractions and its implications for cross-shore sediment transport: A conceptual model. *Marine Geology*, 135(1–4), pp.15–33.

Hay, G.J. & Castilla, G., 2008. Geographic object-based image analysis (GEOBIA): A new name for a new discipline. *Lecture notes in geoinformation and cartography*, pp.75–89. Available at: http://link.springer.com/chapter/10.1007/978-3-540-77058-9_4.

Hell, B. et al., 2012. The use of bathymetric data in society and science: A review from the Baltic Sea. *Ambio*, 41(2), pp.138–150.

Hutchinson, M.F., 2011. ANUDEM User Guide 5.3. , (August).

Konicki, K.M. & Holman, R.A., 2000. *The statistics and kinematics of transverse sand bars on an open coast*,

Li, J. & Heap, A.D., 2014. Spatial interpolation methods applied in the environmental sciences: A review. *Environmental Modelling and Software*, 53, pp.173–189. Available at: http://dx.doi.org/10.1016/j.envsoft.2013.12.008.

Perry, M., 2013. Zonal Statistics, Github Repository. Available at: https://gist.github.com/perrygeo/5667173.

QGIS Development Team - Open Source Geospatial Foundation, 2009. QGIS geographic Information System. Available at: http://qgis.osgeo.org.

Razafindrazaka, F., 2009. Delaunay Triangulation Algorithm and Application to Terrain Generation. , (May), pp.2–12.

Reeve, D. et al., 2007. An investigation of the multi-scale temporal variability of beach profiles at Duck using wavelet packet transforms. *Coastal Engineering*, 54(5), pp.401–415.

RIKZ, 1996. *Evaluatie van zandsuppleties aan de Nederlandse kust 1975-1994, een morfologische beschouwing*,

van Rossum, G., 1995. Python tutorial Technical Report CS-R9526, centrom voor Wiskunde en Informatica.

Ruessink, B.G. & Kroon, A., 1994. The behaviour of a multiple bar system in the nearshore zone of Terschelling, the Netherlands: 1965-1993. *Marine Geology*, 121(3–4), pp.187–197.

Scariano, S.M. & Davenport, J.M., 1984. The effects of Violations of Independence Assumptions in One-Way ANOVA. *American Statistical Association*, 41(2), pp.123–129.

Schumm, S., 1956. Evolution of drainage systems and slopes in badland at Peth Amboy, New Jersey. *Geological Society of America Bulletin*, 67(5), pp.597–646. Available at: http://gsabulletin.gsapubs.org/content/67/8/957.short.

Short, A.D., 1999. *Handbook of beach and shoreface morphodynamics* A. D. Short, ed., New York.

Southgate, H.N., 2011. Data-based yearly forecasting of beach volumes along the Dutch North Sea coast. *Coastal Engineering*, 58(8), pp.749–760. Available at: http://dx.doi.org/10.1016/j.coastaleng.2011.03.011.

van Thiel de Vries, J.S.M. et al., 2008. Analysis of dune erosion processes in large-scale flume experiments. *Coastal Engineering*, 55(12), pp.1028–1040. Available at: http://dx.doi.org/10.1016/j.coastaleng.2008.04.004.

de Vroeg, J.H., 1987. Schematisering brandingsruggen met behulp van jaarlijkse kustmetingen.

Wahba, G., 1990. *Spline models for Observational data*,

Walstra, D.J.R. et al., 2012. On bar growth and decay during interannual net offshore migration. *Coastal Engineering*, 60(1), pp.190–200. Available at: http://dx.doi.org/10.1016/j.coastaleng.2011.10.002.

Wang, P., Ebersole, B. a. & Smith, E.R., 2003. Beach-Profile Evolution under Spilling and Plunging Breakers. *Journal of Waterway, Port, Coastal, and Ocean Engineering*, 129(1), pp.41–46.

Wijnberg, K.M. & Kroon, A., 2002. Barred beaches. *Geomorphology*, 48(1–3), pp.103–120.

Wu, Y.H., Hung, M.C. & Patton, J., 2013. Assessment and visualization of spatial interpolation of soil pH values in farmland. *Precision Agriculture*, 14(6), pp.565–585.

Appendix A – Roland van Zoest, Polyon spider (2017).

```
import sys, os, arcpy, math, re

'''''
ArcGIS-Tool-Script
Creeert een lijnen-featureclass met daarin, per polygon, alle lijnstukken die getrokken
kunnen worden tussen de vertices van dat polygon.
Omdat zogenaamde "curved rings" geen vertex-punten hebben, worden polygonen
van dat type geometry overgeslagen.

Vrij voor gebruik binnen Wageningen-UR.

Februari 2016

Roland van Zoest
GeoDesk
Wageningen-UR
'''

# ==============================================================================

DoPrint = os.path.basename(sys.executable) in [ 'Pythonwin.exe', 'pythonw.exe' ]
DoPrint = DoPrint or ( os.path.basename(sys.executable) == 'ArcMap.exe' )

# ------------------------------------------------------------------------------

def DoMessage ( Msg ) :
  if DoPrint : print Msg
  arcpy.AddMessage ( Msg )

# ------------------------------------------------------------------------------

def DoWarning ( ) :
  Msg = "... CONTINUE after warning ..."
  if DoPrint : print Msg
  arcpy.AddWarning ( Msg )

# ------------------------------------------------------------------------------

def DoError ( ) :
  Msg = "... EXIT after error ..."
  if DoPrint : print Msg
  arcpy.AddError ( Msg )
  sys.exit()

# ------------------------------------------------------------------------------

def DoUsage ( ) :
  Msg = 'Usage:  %s  <Polygons>  <CountField>  <Points>' \
        % os.path.basename ( sys.argv[0] )
  DoMessage(Msg)
  DoError()

# ==============================================================================

def MyCount ( Table ) :

  try :
    Res = int ( arcpy.GetCount_management ( Table ).getOutput(0) )
  except :
    Res = -1

```

```
  return Res

# ---------------------------------------------------------------------------

def MaakLijn ( PntFrom, PntTo ) :

  MyArr = arcpy.Array ( [ arcpy.Point ( PntFrom.X, PntFrom.Y ),
                          arcpy.Point ( PntTo.X,   PntTo.Y   ) ] )

  MyPolyLine = arcpy.Polyline ( MyArr, SpRf )

  return MyPolyLine

# ---------------------------------------------------------------------------

def Schrijven ( P1, P2, L, H ) :

  Line_Forw = MaakLijn ( P1, P2 ) ; Angle_Forw = H % 360
  Line_Back = MaakLijn ( P2, P1 ) ; Angle_Back = ( H + 180 ) % 360

  OK = True
  if JustWithin :
    if ExclBoundary :
      OK = Line_Forw.within ( P_Shp )
    else :
      OK = Line_Forw.within ( P_Shp, 'BOUNDARY' )

  if OK :
    if Double :
      LinCur.insertRow ( [ Line_Forw, P_ID, I1, I2, L, Angle_Forw ] )
      LinCur.insertRow ( [ Line_Back, P_ID, I2, I1, L, Angle_Back ] )
    else :
      if Angle_Forw < 180 :  LinCur.insertRow ( [ Line_Forw, P_ID, I1, I2, L, Angle_Forw ] )
      else :                 LinCur.insertRow ( [ Line_Back, P_ID, I2, I1, L, Angle_Back ] )

  return

# ---------------------------------------------------------------------------

    def GetAngle ( dX, dY, L ) :

      # De hoek, radialen, 1e en 4e kwadrant
      Rad = math.asin ( dY / L )    # is van -Pi/2 tot Pi/2

      # In graden
      Dgr = math.degrees ( Rad )    # is van -90 tot 90

      if ( dX < 0.0 ) :
        # Correctie voor 2e en 3e kwadrant
        Dgr = 180 - Dgr             # is van 90 tot 270

      # Dgr is nu de wiskundig hoek in graden rond de gehele cirkel
      # Omwerken naar kompas-richting : Omkeren en 90 erbij
      Dgr = 90 - Dgr

      # Netjes moduleren naar 0-360
      Dgr = Dgr % 360               # is van 0 tot 360

      return Dgr

    # ---------------------------------------------------------------------------

    def Rekenen ( P1, P2 ) :
```

```
  dX = ( P2.X - P1.X )
  dY = ( P2.Y - P1.Y )
  dXY = math.sqrt ( dX**2 + dY**2 )  ## of: math.hypot ( dX, dY )

  if ( dXY == 0.0 ) : Hoek = float('NaN')
  else :              Hoek = GetAngle ( dX, dY, dXY )

  return dXY, Hoek

# ------------------------------------------------------------------------------

ArgCnt = len ( sys.argv )

Msg = '- '*30
DoMessage ( Msg )

##for A in sys.argv :
##  DoMessage ( ' - "%s"' % str(A) )

# Geen argumenten-check, dat doet de GeoProcessor wel ...
PlgTab = sys.argv[1]
IDfld  = sys.argv[2]
LinTab = sys.argv[3]

reTrue  = '^(T(RUE)?)|(Y(ES)?)|(J(A)?)|(1)'   # voor bij default = False
reFalse = '^(F(ALSE)?)|(N(O)?)|(N(EE)?)|(0)'  # voor bij default = True  ( altijd met not ! )

JustWithin   = not bool ( re.match ( reFalse, sys.argv[4].upper() ) )
ExclBoundary = not bool ( re.match ( reFalse, sys.argv[5].upper() ) )
Double       =     bool ( re.match ( reTrue,  sys.argv[6].upper() ) )

Msg = 'Polygons IN : %s' % PlgTab ; DoMessage(Msg)
Msg = 'ID field : %s' % IDfld ; DoMessage(Msg)
Msg = 'Lines OUT : %s' % LinTab ; DoMessage(Msg)
Msg = 'JustWithin : %s' % JustWithin ; DoMessage(Msg)
Msg = 'ExclBoundary : %s' % ExclBoundary ; DoMessage(Msg)
Msg = 'Double : %s' % Double ; DoMessage(Msg)

# Get the SpatialReference by "Describe"
Dscrb = arcpy.Describe ( PlgTab )
SpRf = Dscrb.spatialReference
Msg = 'Spatial Reference : "%s"' % SpRf.name
DoMessage(Msg)

# Creeer de (lege) Line Feature Class
arcpy.CreateFeatureclass_management ( out_path = os.path.dirname  ( LinTab ),
                                      out_name = os.path.basename ( LinTab ),
                                      geometry_type = 'POLYLINE',
                                      spatial_reference = SpRf )
arcpy.AddField_management ( LinTab, 'PolygonID', 'TEXT'  )
arcpy.AddField_management ( LinTab, 'VxFrom',    'SHORT' )
arcpy.AddField_management ( LinTab, 'VxTo',      'SHORT' )
arcpy.AddField_management ( LinTab, 'Length',    'FLOAT' )
arcpy.AddField_management ( LinTab, 'Heading',   'FLOAT' )

# Maak een InsertCursor voor LinTab om de lijntjes in te kunnen voeren
LinFlds = [ 'SHAPE@', 'PolygonID', 'VxFrom', 'VxTo', 'Length', 'Heading' ]
LinCur = arcpy.da.InsertCursor ( LinTab, LinFlds )

# Verwerk alle (geselecteerde) polygon-records
# d.m.v. een SearchCursor
PlgFlds = [ 'SHAPE@', IDfld ]
with arcpy.da.SearchCursor ( PlgTab, PlgFlds ) as PlgCur :
  for PlgRec in PlgCur :
    P_Shp = PlgRec[0]
```

```
        P_ID = PlgRec[1]
        if P_Shp.JSON.lower().startswith ( '{"curverings":' ) :
          Msg = '! Polygon "%s" : Curved polygons are not supported !' % P_ID
          DoMessage ( Msg )
          DoWarning()
          continue
        Parts = P_Shp.getPart()
        VrtCnt = 0
        for Part in Parts :
          N = len ( Part )
          Pnt1 = Part[0]
          Pnt2 = Part[N-1]
          if Pnt1.equals(Pnt2) :
            # Eerste en laatste vertex zijn gelijk
            N = N - 1
          LenSum = 0.0
          for I1 in range ( 1, N ) :
            Pnt1 = Part[I1]
            if Pnt1 is None :
              # Marker for an inner ring, skip this non-vertex
              VrtCnt -= 1
              continue
            for I2 in range ( 0, I1 ) :
              Pnt2 = Part[I2]
              if Pnt2 is None :
                # Marker for an inner ring, skip this non-vertex
                continue
              Lengte, Hoek = Rekenen ( Pnt1, Pnt2 )
              if Lengte > 0.0 : Schrijven ( Pnt1, Pnt2, Lengte, Hoek )
              ##print 'van %3i  naar %3i  : %10.1f %7.2f' % ( I1, I2, Lengte, Hoek )
            ##print '----------'
          ##print '=========='
          VrtCnt += N
        Msg = 'Polygon "%s" has %s part(s) and %s vertices' % ( str(P_ID), str(len(Parts)), str(VrtCnt) )
        DoMessage ( Msg )

del LinCur

##arcpy.SetParameterAsText ( 2, LinTab )

Msg = 'Created %i straight lines in "%s"' % ( MyCount(LinTab), os.path.basename(LinTab) )
DoMessage ( Msg )
Msg = '- '*30
DoMessage ( Msg )
```

Appendix B – Table of contents digital appendix

- Report (both .docx as .pdf format)
- Midterm and Final presentation
- Raw data
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- Literature