Does the Dutch shoreface change?

The deviation within the migration pattern of near shore sandbars

Nicky van Nunen
6310338
n.j.n.vannunen@students.uu.nl
Supervisor: dr.ir. Ron van Lammeren
Responsible professor: dr.ir. Lammert Kooistra

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Supervisor Wageningen University: dr.ir. Ron van Lammeren

Responsible Professor Wageningen University: dr.ir. Lammert Kooistra

Contact information:

Nicky van Nunen

n.j.n.vannunen@students.uu.nl / n_v_nunen@hotmail.com

UU student number: 6310338

WUR student number: 941202611050

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Utrecht University, Wageningen University, TU Delft and TU Twente,

The Netherlands.

Acknowledgements

Abstract

Coastal areas are interesting places where many activities take place. For building settlements, coastal areas have always been a popular place. Besides this, coastal areas and especially beaches are places where recreation exists. The Netherlands is an example of a country where the coast is of importance, especially because most of the Netherlands lies below sea level.

At the coastal areas, several dynamic systems are present which are not always visible with the human eye. I one of those dynamic and complex systems, sandbars plays a big role. Sandbars are sandy shoals that occur in nearshore areas. Sandbars play a big role in sandbar protection and thus are interesting to investigate. Mostly because sandbars are not a static phenomenon, they are dynamic and move over time. Those changes have an impact on for example the sea bed and the impact of waves. When there is a deviation within the change, this could have a major impact on coastal areas and their settlements. Therefore it is important to investigate the changes of sandbar over time. This research will look at the deviations within the cycle of sandbar movement over a timeframe from 1965 till 2018.

As already said sandbars are shoal that occur in nearshore areas. A clear definition can be given for this research, but the definition depends on the application of the term. For example, sandbars could also appear in river areas. This could have an impact on the specific definition that can be used in research.

The detection of sandbars can be done by different methods. It depends on the data which is available. In this research, JARKUS data is used. These datasets consist of points presented in transects that are situated perpendicular to the Dutch coast. Those points all have a depth measurement. All datasets from 1965 till 2018 are built up the same way. To detect sandbars, and especially their form, in this research it is chosen to use a reference surface. This is a surface made out of the deepest point per transect and the shoreline. Those points are formed to a surface with a constant slope. When comparing this reference surface with the original data, the form of sandbars can be detected because sandbars became visible above the reference surface.

After the detection of the sandbars for each year, a time-series analysis has been done to see if there were patterns and possible deviations visible. The analysis resulted in different patterns that could be distinguished related to the movement of sandbars over time. Related to literature, the patterns were visible in the results. But, there was no common pattern visible and some patterns were found that were not present in literature. Therefore it is not possible to say that there is a clear pattern visible in the migration of sandbars.

Besides the migration of sandbars, the change in shape is also analysed. This has been done with the Polsby-Popper test. The test resulted in different kind of shapes of sandbars over time. The results show an interesting relation between the shape and the area of a sandbar. When the area of the sandbar shrinks over time, the Polsby-Popper value becomes lower. Thus, when the area of the sandbar became smaller the sandbar's shape becomes more elongated. Besides this, the relation also exists when reasoning the other way: when the area of the sandbar increase over time, the Polsby-Popper value becomes higher. This means that when the sandbar becomes bigger over time, the shape of the sandbar becomes more round and compact.

To see if the results of this research could be justified, a sensitivity analysis has been done. Here, two factors were changed to see if they affect the results. First, other data has been used for generating the reference surface which is used to detect sandbars. This resulted in a possible impact on the number of detected sandbars. The amount of sandbars in the year which is used to generate

the reference surface is higher than the surrounding years. The impact of this factor must be further investigated to see if this impact is random or significant.

Besides the change of the reference surface, the smoothing technique for calculating the Polsby-Popper test has also been researched. Another smoothing technique resulted in no significant evidence that the means of the Polsby-Popper test differs. This means that the smoothing technique has no impact on the mean of the Polsby-Popper test.

This research is not easy to compare to other research because other research mainly looked at the highest point of a sandbar at each transect rather than the shape of the sandbar.

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List of Abbreviations

.csv	comma-separated values file
DBM	Digital Bathymetry Model
DEM	Digital Elevation Model
DTM	Digital Terrain Model
JARKUS	JAaRlijkseKUStlodingen
NAP	Normaal Amsterdams Peil
PEAK	Polynominal Aprroximation with Exponential Kernel
PP-test	Polsby-Popper test
TIN	Triangulated Irregular Network

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1. Introduction

1.1 Context

Since the first human civilisations, settlements were often built on coastal areas. This has been done mostly for strategic reasons, like mobility. Nowadays, most settlements are still built near coastal areas but not only for the strategic reasons, but also recreation became more important.

Worldwide, 40% of the coastline consists of beaches with sand or gravel (Bird, 2000). These coastlines have all complex and dynamic behaviours. Sandbars are part of those systems. Sandbars play an important role in coastal protection. Those sandbars are not located at one spot but migrate over time. Typically, a sandbar goes through three different stages during its existence (Ruessink & Kroon, 1994). In this first stage, the sandbar is generated in the inner nearshore in water depths of 1 to 2 meters. Thereafter, the sandbar migrates offshore through the surf zone to depths of 4 to 6 meters. Finally, it decays in the outer nearshore zone at depths of 5 to 7 meters (Ruessink & Terwindt, 2000). This means a sandbar will have a pattern of movement.

When the migration of sandbars changes the shape of the sea bed, the direction and power of the waves reaching the coast can be changed (Timmer, 2017). The condition and location of the sandbar also influence the impact of waves. Sandbars closer to the coast and low sandbars let waves come onshore with more power than higher sandbars further from the coast (Cambazoglu, 2009). Besides the direct influence of sandbars on waves reaching the coast, and indirect influence on dune development can be monitored (Aleman et al., 2011). Dunes protect the coastal areas from the water. 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, coastal areas become vulnerable. Besides the Dutch coast has a complex and dynamic behaviour, partly due to her sandy coast (B. G. Ruessink & Terwindt, 2000).

With this given, it is important to study the dynamic behaviour of the coast of the Netherlands. The pattern of sandbar movement plays an important role in this dynamic behaviour. When trying to detect patterns along the Dutch coast, it is possible to see if there are any deviations visible in those patterns. This could be interesting when looking at global impacts like climate change. Because there is a change that the movement of sandbars will result in different dynamic behaviour, for example, the impact of water reaching the Dutch coastal areas can change.

Through the years, research has been done related to sandbars and coastal behaviour. One of the products that have been used for studies is the JARKUS dataset, which is made available by Rijkswaterstaat. Rijkswaterstaat is a governmental organisation which have executive tasks of the Ministry of Infrastructure and Environment. One of the products they made is JARKUS. the product consists of yearly measurements of the bathymetry of the North Sea close to the Dutch shore. The measurements started back in 1963 and are still ongoing. This means that monitoring the Dutch coastal areas is not a new phenomenon but investigating the movements of sandbars at a national scale is not been done until now.

1.2 Problem definition

This is not the first time nearshore sandbars have been studied (Exon, 1975; Konicki & Holman, 2000; Ruessink & Terwindt, 2000). Although, the focus on research over time has been changed. From the '50s till the '70s the focus was mainly on positioning on short time scales due to the lack of equipment at the time. When the equipment developed over time, the focus changed. The time scale of the research object prolonged and a change of focus can be detected. The focus on the positioning of sandbars changed to the focus on the processes behind the migration of sandbars over time. Although the improvement of technology motivated to study sandbars on a larger temporal and spatial scales, research is still done on smaller spatial and temporal scales.

This project will use a larger temporal and spatial scale to explore the coast of the Netherlands. The problem that needs to be solved in this research is related to patterns of sandbar movement along the Dutch coast. In literature, different patterns of sandbar movements can be found. As said before, different external variables can affect those sandbar movements. If this is the case, deviations within the pattern can be detected, which could be a problem for the Dutch coast on longer terms. This because with the current climate change, the water level is rising also at the Dutch coastal areas. When sandbars are changing in unexpected ways, this could be a threat to the Dutch coastal areas and hinterland because the Netherlands is a low-lying country (~33% of the land is located under mean sea level) and therefore vulnerable to floods or other water-related events. Sandbars are namely the primary breakers of waves within the nearshore zone, as seen in figure 1.

This project will use the available JARKUS dataset to explore the sandbar dynamics along the coast of the Netherlands. This study will look at deviations within patterns of sandbar movements over time. Firstly, this will be done to see if there are any patterns visible when looking at these movements along the Dutch coast. Furthermore, not only the cycle or patterns of sandbars are important in this project but also the change within the pattern, the deviation. This will be explained by several sandbar characteristics like the change in shape and the change over time in movement. The goal of this project is to get information about the pattern of sandbar movements and the possible deviations within the pattern, which may indicate changes that can be important in future developments and events.
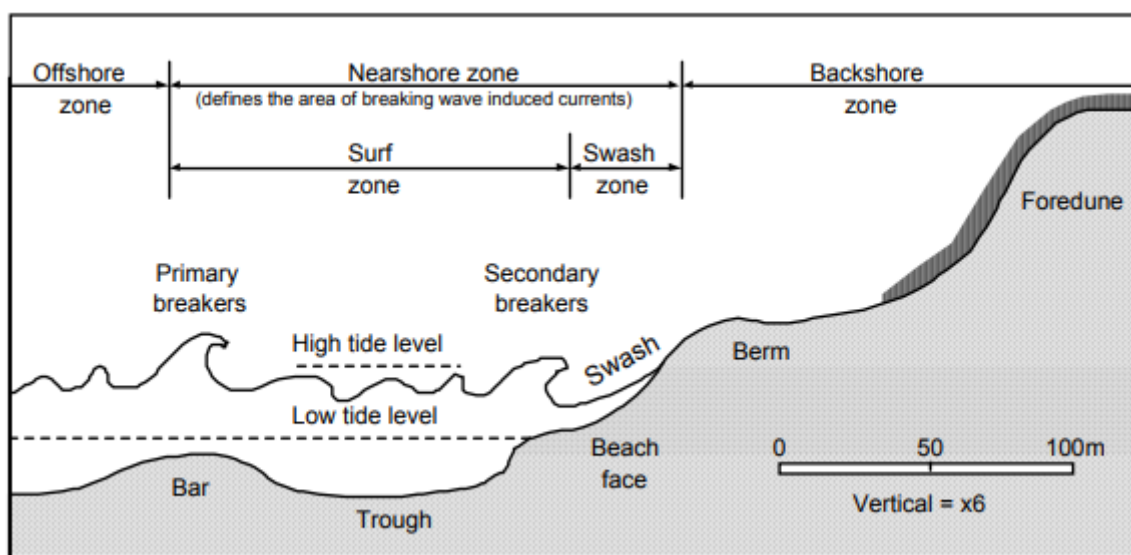
Figure 1: Schematic representation of a cross-section of the coast showing the location of sandbars (Bailey & Shand, 2002)

1.3 Research objectives and research questions

The objective of this thesis is to provide an insight into the possible deviations within the pattern of sandbar movement near the Dutch coastal areas over a timeframe from 1965 to 2018. These insights could be important in future developments related to coastal protection. Scientifically, these insights will give a better overview of deviations within patterns that maybe can be linked to bigger events like climate change.

To explore patterns, data with a timeframe must be used. When having data on different time steps, patterns can be detected. These timesteps can be seen in different ways. There are different cycles that represent a timeframe, like the moon cycle or a yearly cycle. In this research, a yearly cycle will be used to detect and analyse the change of sandbars. To be able to realise the research objective of this thesis, the following main question is formulated:

What deviations within the cycle of sandbar movement can be detected, on the Dutch coastal areas, over time (1965 – 2018)?

To be able to formulate an answer to this main question, the research is divided into sub-questions that will focus each on different aspects of this project. The research questions are as followed:

1. What is the definition of sandbars and sandbar movement?
2. How can sandbars be detected?
3. How do sandbars change over time, is there a cycle or pattern visible?
4. To what extent does a change of parameters affect the results?

1.4 Scope of the project

It is important to have a clear scope when starting this research. Firstly, the area in this project is defined by the sixteen coastal areas as seen in figure 2. This means that not all of the Dutch coast will be included in this project. The areas around the Ijsselmeer are excluded even as the coastal areas of Groningen and Friesland. Only the forming of sandbars directly located at the North Sea will be included in this project.

Figure 2: The coastal sections of the Netherlands that will be studied in this research (own work)

Another important note is the data that is included in this project is from 1965 till 2018. This means that the changes of sandbars before 1965 are excluded in this project, simply because there is no data available of that time frame. It can be the case that the data from 1963 and further on is not fully complete, when exploring the time scale of the project this given should be considered. For example, if there is only fully available data from 1970 till 2005, there could be a chance that those data are included in this research and all the other data available will be excluded because of incompleteness. Also, the data till 2008 could be different than de data from 2009 till 2018. This because the first dataset is gathered through university. Only data until 2008 was present. The data from 2009 till 2018 is gathered through contact with Rijkswaterstaat. The format could be different and also the pre-processing done by Rijkswaterstaat could differ. It is important to look at this before the start of any analysis.

1.5 Reading guide

This report consists of different chapters. Chapter 1 was an overall introduction to the topic of this research including the research questions and objectives.

Next, chapter 2 gives a more in-depth view of the topic as a theoretical framework. First, it will explain the term sandbars and give information about the possible patterns of sandbar migration. After this, concepts of GIS and time series analysis which are important to know related to this research are explained. The chapter also gives insight into the possible methods that can be used when analysing sandbar detection as preparation for chapter 3.

Chapter 3 gives an insight into the used methodology in the research. First, the case study will be explained followed by the used data. Then, the research steps that are taken are discussed followed by the used methods per research question. At the end of the chapter, some information is given about the used software.

In chapter 4, the results of the analyses are discussed. First, the reference surface will be discussed followed by the number of sandbars that are detected. Then, something will be said about the shape of the sandbars. After the general results of the detected sandbars, the results of the time-series analysis are discussed. First, the change of location of the sandbars and then the change in the shape of the sandbar. In this chapter the discussion of the results is included, which are also summarised in chapter 7.

To see if the results can be validated, chapter 5 gives the result of a sensitivity analysis. The sensitivity analysis can be divided into two parts: the change of reference surface and the change of the smoothing technique. First, the effects on the data when changes the reference surface will be discussed and after this the effects on the results when changing the smoothing technique will be discussed.

Chapter 6 will give an answer to the research questions that were stated in chapter 1. In the end, chapter 7 will discuss the results related to other research and will give some recommendations for further research.

2. Theoretical Framework

In this chapter, the theoretical background regarding the movements pattern of sandbars will be presented. To do so, separate terms related to the movement of sandbars will be explored. First, the definition of sandbars is explained followed by the possible patterns of sandbars movements. To do analysis related to these terms, some concepts of GIS and time series analysis are important to mention. Terms related to that analysis are also been described in the theoretical framework. In the end, possible methods related to sandbar detection are explained, where the used methods will be explained in chapter 3.

2.1 Sandbars

The search for a clear definition of the term sandbar starts with a look in a Dutch dictionary called 'Van Dale'. It says that a sandbar (or in Dutch 'zandbank') is a sandy shoal in a river or sea (van Dale, 2019). Within this broad definition of sandbars, different types can be distinguished. As the definition of the van Dale suggested, sandbars can appear in seas or river. Because rivers have a different dynamic system than sea areas, the types of sandbars that can be found in both areas are different (Jin et al., 2017). Because this research aims at the sandbars located in the sea, the definitions of sandbars in rivers will not be further researched.

So, when looking at sandbars that can appear in the sea, different types can be distinguished. Which type of sandbar appears where is partly depending on which kind of beach is present (King & Williams, 1949). There are two types of beaches that will each have its own kind of sandbar appeared. Firstly, non-tidal beaches, where the sea is tideless. Tideless beaches are very common in the Mediterranean and Baltic seas (King & Williams, 1949). The most common pattern of sandbars that can appear is parallel bars as seen in figure 4. Parallel bars are mostly one to four parallel bars which are comparatively straight and parallel to the waterline. This type of sandbar is formed below sea-level and never exposed above the water surface (King & Williams, 1949). This is due to the tideless beach where the water level is almost constant.

The other type of sandbars can be found at tidal beaches. These are called crescentic sandbars (King & Williams, 1949). They are shaped like crescent moons parallel to the shore as seen in figure 3 and 5 (van Enckevort et al., 2004). These sandbars are exposed at low tide and are intersected by drainage channels at right angles to the waterline. At the Dutch coastal area, several of those type of sandbars have been found in the past (van Enckevort et al., 2004). The first report that has found crescentic sandbars near the Dutch coast is written by Ruessink in 1992. This research was focused on the coast of Terschelling. Because in the past some examples of crescentic sandbars
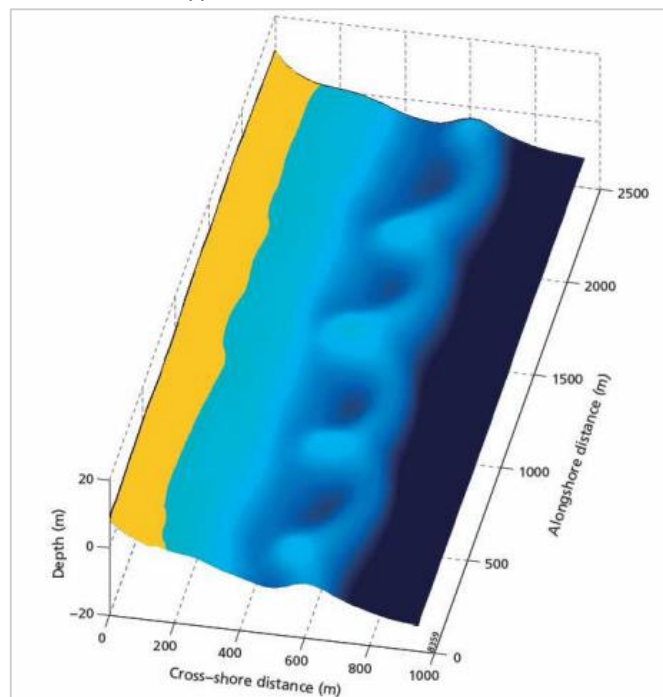
Figure 3: Bathymetry of a beach with a crescentic sandbar (Ruessink, Price, & Castelle, 2013)

have been found near the Dutch shoreface, it is possible that in this research more examples can be found of this type sandbar.

Figure 3 and 5 suggests that with this type of sandbar, only one sandbar can appear. This could be the case, but also more sandbars can appear in a double sandbar system (Ruessink, Price, & Castelle, 2013). This system suggests that there are two, or more bars. One of the bars is a more landward inner bar and the others are seaward outer bars. Various observations indicate that the inner bar differs from the outer bars (Ruessink et al., 2013). The inner bar is remarkably smaller than the outer bar(s).
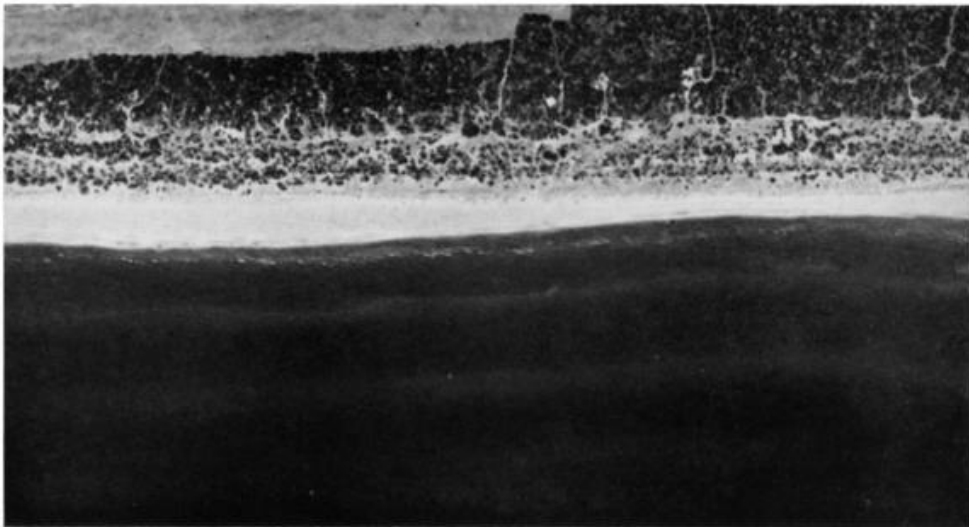
Figure 4: Example of straight parallel bars on a beach south of Rome (King & Williams, 1949)
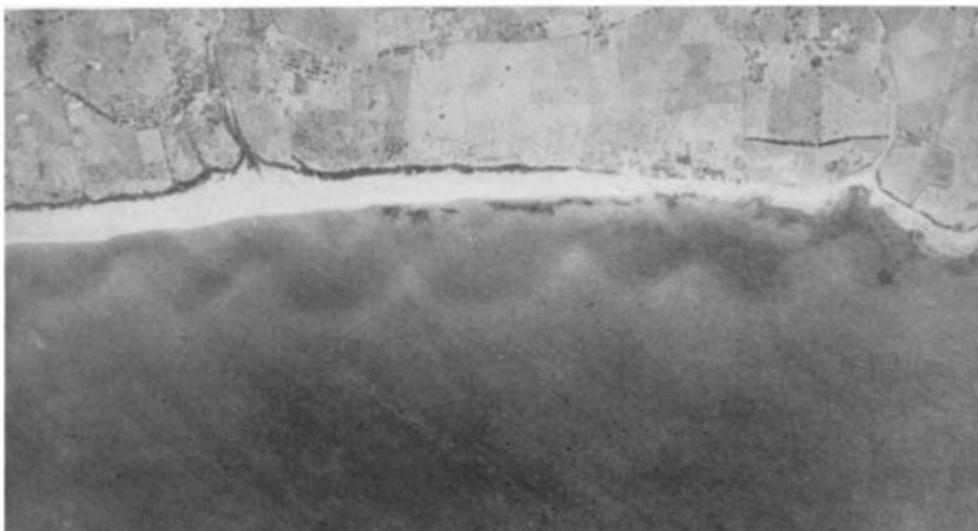
Figure 5: Example of crescentic bars at the Gulf of Salerno (King & Williams, 1949)

2.2 Patterns of sandbar migration

The evolution of sandbars is, in general, driven by tides, waves, meteorologically induced surge and the supply of sediment, all of which interact over a broad range of time scales (Reeve, Horrillo-Caraballo, & Magar, 2008).

When looking at the Dutch coastline sub-tide sandbars and intertidal sandbars are visible (Van der Grinten & Ruessink, 2012). The sub-tide banks were situated around 300 and 500 meters off the coast on a depth of one and three meters. The intertidal sandbars, which occur with eb, are located close to the coast. These sandbars become visible with eb.

This research will look at the sub-tide banks that are located below sea level. A characteristic of that kind of sandbars is the fact that they are not always located at the same spot, their location can change over time: sometimes they come closer to the coast and then move back (Van der Grinten & Ruessink, 2012). Van Enckevort and Ruessink (2003) show that sandbars are moving away from the coast. Figure 6 shows this movement. In this figure, the striped lines represent the movement of sandbars through time at the coast of Noordwijk. Besides the movements of sandbars, this figure also shows the disappearance of sandbars. For example, the outermost sandbar disappeared in 1982 around 700 meters off the coastal area. With this information, it

Figure 6: Averaged sandbar profile of the coastal area in Noordwijk (Van der Grinten & Ruessink, 2012)

can be said that those sandbars have a cycle of approximately 5 years and move 50 till 100 meters a year before they finally disappeared. This does not mean that at every location this cycle is visible. It could be that this is a local phenomenon which will not be visible when looking at a smaller scale, like the coastal areas of the Netherlands.

Research has been done where different timescales are used to see if there are patterns visible related to the movement of sandbars (Van der Grinten & Ruessink, 2012; Van Enckevort & Ruessink, 2003). Different timescales have been used, like seasonal, yearly and short timescales. Small timescales like seasonal or short did not result in clear cycles of sandbar movements. Cycles of movement became visible mostly when looking at yearly obtained data.

There are external events that can affect the movements of sandbars, an example that is implemented at the Dutch coast is beach replenishment. Beach replenishment is a method where sand is added at the beach to expand the coast (Stichting de Noordzee, n.d.). This method is used for coastal protection. Beach replenishment has an impact on the movement of sandbars. In 2008 after such a beach replenishment, the migration of sandbars increased in terms of speed (Van der Grinten & Ruessink, 2012). Not only at the location where the beach replenishment took place, but also the surrounding areas where affected related to this event.

2.3 Concepts of GIS and time series analysis

2.3.1 Surfaces

A surface is a continuous field of data (like elevation) (Longley, Goodchild, Maguire, & Rhind, 2011). This type of data is the basis for many types of GIS analysis. A continuous field represents the real world as a finite number of variables each one defined at every possible position. The representing of a surface can be done by a digital terrain model (DTM). There are different ways of representing a surface by this model. Firstly, a raster representation can be given. The raster representation of a surface of elevation is called a digital elevation model (DEM). The other way is a vector-based representation called Triangulated Irregular Network (TIN). Where a DEM uses pixels to represent a continuous surface, a TIN uses non-overlapping triangles. Both types can be generated through interpolation of data.

Spatial interpolation is a process of 'guesswork' in an attempt to make a reasonable estimate of the value of a continuous field at places where the field has not actually been measured (Longley et al., 2011). There are various methods for interpolating data, but all of them use distance as a basis. It could be said that all interpolation methods are based on Tobler's First Law of Geography: 'nearby things are more related than distant things' (Longley et al., 2011).

Different interpolation methods have different advantages and disadvantages. The choice of which interpolation method will be used is important to reduce errors in the DTM which will be used throughout the rest of the analysis (Krawczyk, 2017).

2.3.2 Spatio-temporal resolution

An important aspect of shoreface analysis is ensuring the spatial and temporal scales of the data match the scale of the processes being studied (Krawczyk, 2017). Within the field of GIS related to time series analysis, various methods exist to change the time scale of data. It cannot be said that every temporal scale can be used on every kind of data. To reduce errors on the original data, the temporal scale must be chosen wisely.

When looking at time series analysis, smoothing the data is a common way to detect trends or periodic cycles in the data. Through an application of local averaging, smoothing ensures that outliers cannot occur (Krawczyk, 2017). This is important because the representation of reality is affected by this noise (Paddenburg & Wachowicz, 2014). With generalising spatial cells, the observed spatiotemporal variations may be affected. To achieve the outlier reduction, two common techniques exist, non-overlapping and overlapping temporal aggregation. Non-overlapping aggregation aggregates data to a specified interval – the analysis interval (e.g. day, week, month, year, etc.). The drawback of this method is that it assumes that data is not related to each other and can be segmented into separate blocks (Krawczyk, 2017). There are different methods for overlapping temporal aggregation. The most common technique is a *simple moving average* smoothing. This technique calculated the averages of subsequent subsets of *n* elements of the original data, where *n* corresponds to the size of the smoothing 'window' (Krawczyk, 2017). The calculated subset replaces the original elements of the series.

Smoothing by GIS can be obtained by changing the cell size through interpolation or aggregation of the data, or by recalculating the value in each raster cell based on a given number of surrounding cells (Krawczyk, 2017). There are some differences between interpolation, aggregation and the recalculating of the raster (focal statistics). Interpolation uses the values of the original raster to fill the output raster with larger cell sizes. Aggregation assigns to each output cell, the mean, median,

sum, minimum or maximum of the input cells falling within the new output cell. Focal statistics applies similar methods as the aggregation method, however, the cell size of the output does not change. This because the output value is based on a moving window.

2.3.3 Deviation within data

Detecting change within location and time is called spatiotemporal change footprint pattern discovery (Zhou, Shekhar, & Ali, 2014). Discovering changes in spatiotemporal data of larger datasets in an increasingly important activity in application domains as climate science and public health. Over the years, researchers have developed numerous techniques to facilitate the research to patterns.

Besides the different techniques that exist to research change, there are also various definitions of spatiotemporal change. There are four different ways which can define the change in data (Zhou et al., 2014):

Change in statistical parameter	Data is assumed to be random samples drawn from an underlying process. A change is thus defined as a shift in the statistical distribution of data.
Change in Actual Value	Based on the actual values of the data. Change is initially modelled in calculus, where a difference between a value and its neighbourhoods in location or time is viewed.
Change in Models Fitted to Data	Focuses on the change in trend/behaviour of the data. A number of function models are fitted to the data where a change in one or more of the models is defined as an instance of change.
Change in Derived Attributes	Some application defines change patterns indirectly. First, they establish a classification or prediction model of the data. Then they run the model and derive new attributes, such as predicted value.

Figure 7: Four definitions of change in data (based on Zhou, Shekhar et al. 2014)

These different change definitions can be researched with different techniques. Change footprints can be subdivided into two dimensions: temporal and spatial. There are four types of Temporal footprints: single snapshot, set of snapshots, point in a long series and interval in a long series (Zhou et al., 2014).

Single snapshot means that the change is purely spatial without any temporal context. Set of snapshots indicates that change is between two or more versions of the same spatial field, like two different satellite images of the same location. The point in a long series refers to a single time instance in a long series of data. The last one, the interval in a long series, is a long-time period in a long series of data.

Spatial footprints can be classified in raster or vector-based. When looking at the raster-based footprints, they can be further classified based on the scale of the pattern namely local, focal and zonal. Vector-based patterns can be classified in point, line, polygons and network footprint patterns.

3. Methodology

In this chapter, the different methodological steps of this study will be described. First, the case study will be described as well as the data used in this research. Then the research steps taken in this research are explained followed by a methodological overview. After the overview, the methods used for pre-processing the data are explained followed by the explanations of methods used to answer the research questions stated in chapter 1.

3.1 Case study

This research features a case study. A case study research begins with the identification of a specific case (Creswell, 2013). The goal is to define a case that can be bounded or described with certain parameters, such as a specific time and place. In this research, time and place are the two most important parameters that must be defined.

When looking at the place of this research, the case can be bounded as seen in figure 2. The study area of this research is the Dutch coastline directly situated at the North Sea. There are 16 coastal sections that all will be explored. The data used to do so is called 'JARKUS'. JARKUS is a raw data set supplied by Rijkswaterstaat. The dataset consists of point measurements in transects from the top of the first dune going seaward. Figure 8 shows an example of those transacts at Texel. The length of the transects therefor varies per location. The distance between two transects is 200 meters. The point data is supplied with distance measurements, depth measurements, an angle and an origin. When looking at the depth measurements, both heights above and beneath sea level are included.
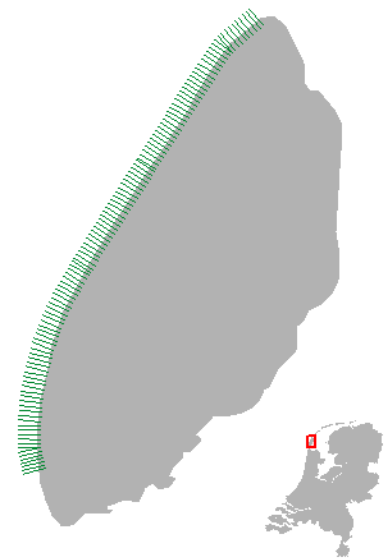
Figure 8: An example of transacts on the coast of Texel

Another important parameter that must be taken into consideration is time. In this research, a dataset of the Dutch coastal area is used. This dataset contains data measured on several steps through time. Yearly, the data is collected of the whole Dutch coast. The data collection always took place outside the stormy season. In this research, the data from 1965 till 2018 is used. This means that there are 54 years represented in the data.

With both given parameters defined, the identification of the case has been done.

3.2 JARKUS data

The JARKUS dataset is a collection of cross-shore bathymetric profiles covering the coast of the Netherlands. Measurements have been made since 1965 on an annual basis, outside the stormy season.

The JARKUS data has been provided by two organisations, as seen in table 1. The JARKUS dataset from 1965 till 2008 is provided by Wageningen University, which is extracted from Rijkswaterstaat. It consists of .csv files with spatial features like an x coordinate and a y coordinate. Also, the z-value (depth) is present in the dataset. Beside these spatial features, information about which coastal area the point is in and at which transect the point belongs is also present.

Data from 2009 till 2018 is provided by Rijkswaterstaat. After contacting several times, a text file with the data was sent. These textfiles contained, even as the data from 1965 till 2008, the x and y

coordinates and the z-value. This means that the data needed for the analysis is present. Besides the spatial information such as the x, y and z coordinates, some information about the day of measurement was included. These datasets did not have information about which coastal area or which transect the data belongs to. In this research, this is not of importance because the location of each point is registered.

All the measurements of both datasets are point measurements along transects perpendicular to the shoreline. The length of the transects varies per location and time. The transects are divided into 16 coastal areas or in Dutch 'kustvakken'. These are from North to South: Schiermonnikoog, Ameland, Terschelling, Vlieland, Texel, Noord-Holland, Rijnland, Delfland, Maasvlakte, Voorne, Goeree, Schouwen, Oosterschelde, Noord-Beveland, Walcheren and Zeeuw-Vlaanderen (see also figure 2).

Table 1: Overview of data

Data	Provider	Type	Complete?
JARKUS 1965 – 2008	Wageningen University	.csv	Yes
JARKUS 2009 – 2017	Rijkswaterstaat	.txt, .jrk	2010: Rijnland & Delfland missing 2011: Rijnland missing
JARKUS 2018	Rijkswaterstaat	.txt	Yes

3.3 Research steps

To answer the main research question, some steps must be taken. These steps are the research questions that are already presented in the research objectives of this project. Research question 1 must be answered before research question 2 can be answered, followed by research questions 3. When all the research questions are answered the main research question can be answered. So, it is not possible to partly answer the first research question and already answering the second research question. The steps that must be taken within the research questions will be explained in the following paragraphs.

An overview of the steps taken in this research can be seen in figure 9. In this figure, it can be seen which steps are needed to answer each research question. Answers to all the research questions are needed to answer the main question of this research. Besides the steps that must be taken to answer the research questions, the methods that have been used in the analysis are also important. An overview of the used methods can be seen in figure 10.
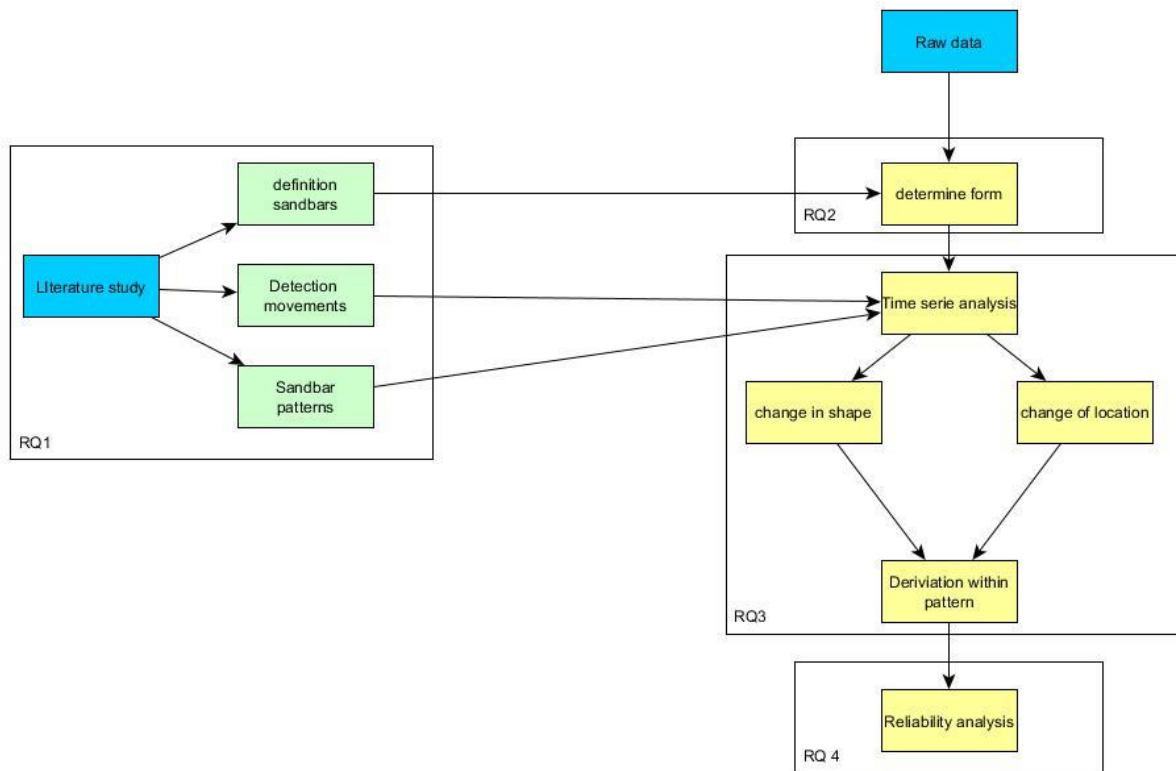
Figure 9: Overview of the steps taken in this research. The yellow blocks represent the data analysis, the blue ones the input and green the output.
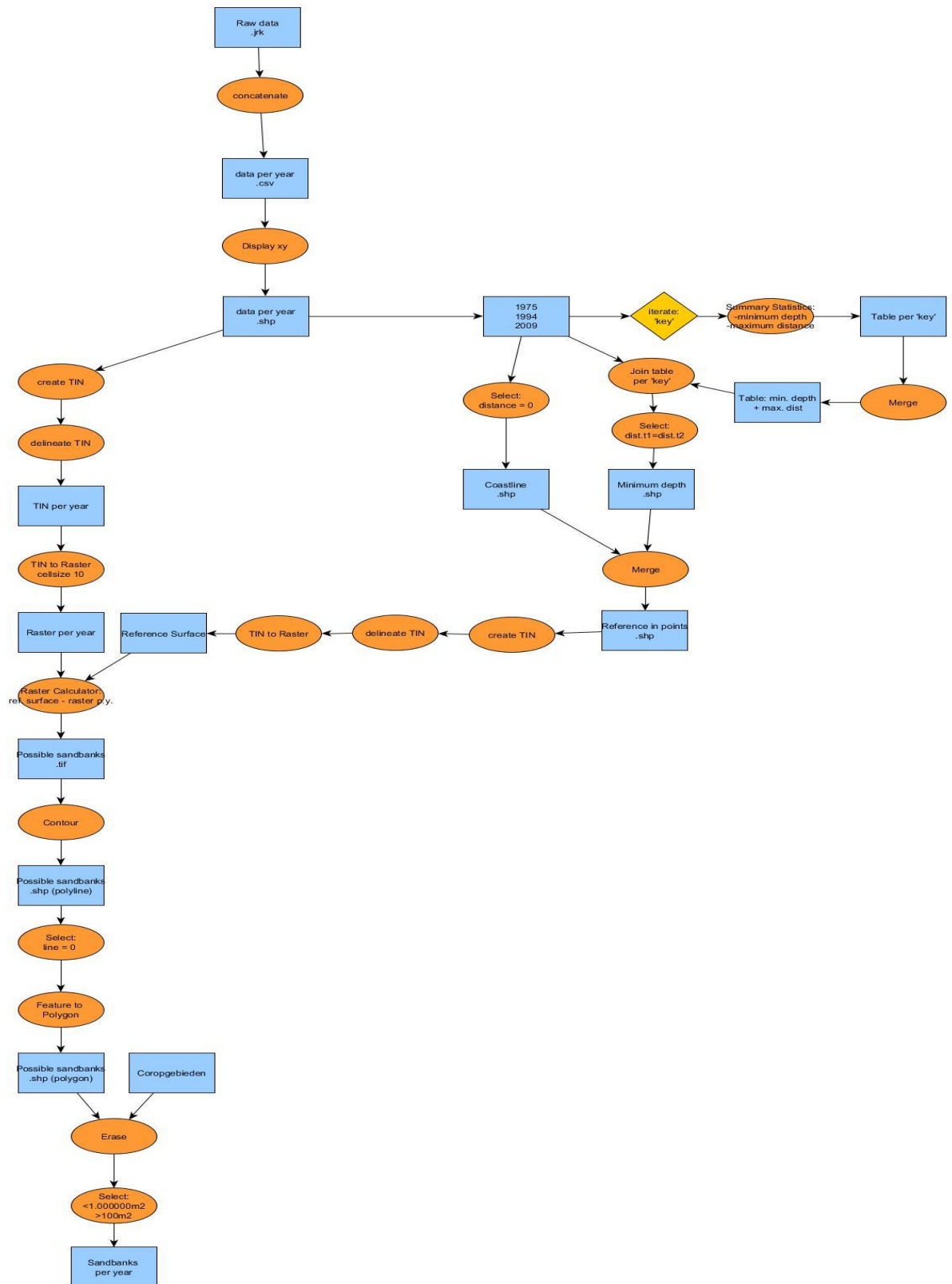
Figure 10: Overview of the methods used in this study. The orange circles are the tool/methods, the blue blocks are data

3.3.1 Data pre-processing

Figure 11: Methods used to pre-process the data
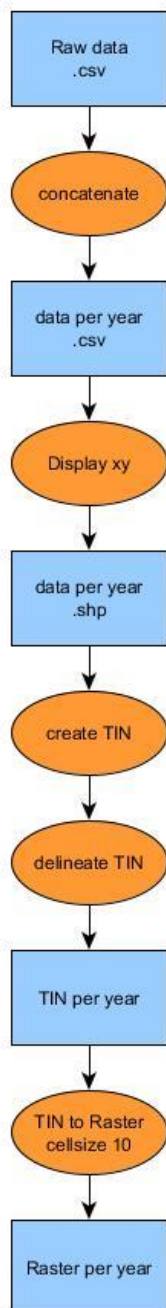
The JARKUS data used in this research is a raw dataset. This means that the data cannot directly be used for analyses. First, some steps must be taken to process the data for usage. These steps can be seen in figure 11.

The JARKUS dataset consists of .csv data. The data is separated in different .csv files per location. In total there are 16 different locations on the Dutch coast, so there are 16 different file maps available. Within these file maps, there are .csv files per year, from 1965 until 2018. In each file map, there were 43 .csv flies present. This resulted in 720 .csv files that must be merged into files per year, so at the end, only 45 .csv files remained. This must be done per year because in this research time series will be explored. To do so, data of the whole Dutch coast per year is needed.

To accomplish this, a python script has been written. In this script the separate .csv files were merged into .csv files per year using the 'concatenate' operation. When this has been done the files can be further processed in ArcGIS.

With the 'display xy' function these JARKUS data can be visualised as point features in a certain coordinate system, in this project RD_New was used as a coordinate system. These points are the basis of the following analysis.

After the visualisation, the data is still not ready to use for analysis. With surface analysis, a surface is needed. The data is not presented in a surface but as separate points with a specific x and y coordinate.

A TIN is created to accomplish a surface that is needed. A TIN is created by a set of points with *x, y* and *z* coordinate values. First, a convex hull is created for a dataset. Next, straight lines that do not cross each other are drawn from interior pints to points on the boundary of the convex hull and to each other (Longley et al., 2011). This divides the convex hull into a set of polygons, which are then divided into triangles by drawing more lines between vertices of the polygons. The delineate tool has been used to remove the lines that were wrongly drawn.

In this study, a TIN surface is not sufficient to perform the analysis. Therefore a DEM must be generated. This is done with the 'TIN to Raster' tool with a pixel size of 10x10 meters.

3.3.2. Reference surface
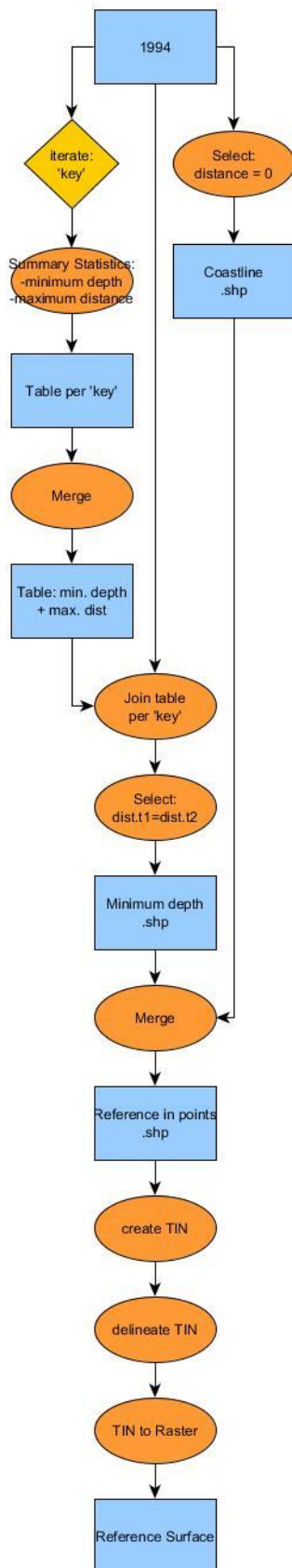
Figure 12: Methods used to generate the reference surface

To determine the shape of each sandbar, a reference surface must be made. The workflow to make a reference surface is visualised in figure 12.

The reference system used in this project has been made with the data of 1994. The reference surface is made with the deepest point of each transact and the zero measurements of each transact. Those numbers must be extracted from the data. To do so, first, the deepest point must be found. This is done through an iteration of the 'key' field within the dataset. What it does is it finds al the same values of 'key'. After done so, the minimum value of the feature 'depth' and the maximum value of the feature 'distance' were generated per 'key'. As a result, tables of each 'key' (each transact) with the minimal depth and maximum distance were saved. To use these results the tables must be merged. The next step is to join the results with the original point data set. This is done by a join of the field 'key'. Then, a selecting has been made where the distance generated in the new table is the same as the distance in the 1994 table. This resulted in a table where for each key the furthest away point is selected and connected to the deepest point in that transact.

Besides the outer points with the deepest measurement of each transects, the points representing the beginning of the coast must be selected. Those are the zero measurements. To get these points, the selection tool will be used. There is a field in the dataset named 'distance' which represents the distance from the point to the coast. When selecting al the zero measurements of this field, the points representing the coastline are found. Then, the two datasets of the deepest measurements and the zero measurements must be merged. This resulted in a shapefile with two points per transect that represents the coastline and the deepest point of the transect.

The next step is a triangulation of the points. This will be done by a TIN because with TIN triangulation a surface with a constant slope can be generated (Pilesjö, 2008).

The data then will be rasterised with the 'TIN to raster' tool, which results in a surface per pixel (pixel size 10x10 meters). This tool creates a raster by interpolating its cell values from the elevation of the input TIN. As a check, the slope of the raster surface has been made. This slope shows an almost constant slope per pixel between the measured points, which will be explained in paragraph 4.1

Because the time of the analysis needs to run in ArcGIS it is chosen for this research to use one reference surface for all the years with data. The one reference surface constructed and used in this study has been generated out of the JARKUS data of 1994. The decision for this dataset was a random one.

3.3.3 RQ1 Definition of sandbars and their patterns

The first research step that has been taken is related to the definition of sandbars and their patterns. This research question tries to give a definition of the term. This is needed because when not having a well-defined term could lead to misunderstandings within the research. To prevent this, a literature study of the term is needed. When having a clear understanding of the term sandbars, there should be no discussion based on this research related to the term. Also, there is more than one theory about the movements and patterns of sandbars. Different theories will be explored to get an overview to answer the main question at the end.

In literature, there are many articles related to the term 'sandbars'. Therefore, a structured search is very important. There are different approaches on how to find suitable literature. Within these approaches, some steps can be taken.

The first step is to discuss where to find suitable literature for research. There are many sources where literature can be found: not only in libraries but also more and more through the internet (Vennix, 2011). To find a definition of sandbars and patterns of movement, the literature on the internet will be searched because it is easier to search on the internet than in libraries. This because there are several websites where you can search specific keywords that lead to interesting articles. In libraries, more steps must be taken to find a useful book or article. Also, when finally finding the book or article it must manually be scanned by the person itself, while internet articles can be scanned by the computer which is more efficient.

The next step is to find the right keywords that are needed to search for the right literature (Geertman, 2017). Keywords can be identified by thinking of the most important terms related to the search purpose. In this research, 'sandbars' and 'patterns' are important terms. To find the right literature the terms needs to be used together; separate they do not result in the needed literature. Other terms that can be used to search are synonyms of the terms needed. For example, a synonym of 'patterns' can be 'design' or 'model'.

When deciding which are the keywords to search, start to search with up-to-date articles from the last 3 to 5 years. With those articles, other articles can be found with the snowball-searching method (Geertman, 2017). The snowball-searching method refers to using the reference list of a paper or the citations to identify additional papers that can be used for the same purpose (Wohlin, 2014). In the end, different suitable documents can be found. The last step to secure that those documents are useful in this research, the title, abstract, introduction and conclusion can be read (Geertman, 2017).

The answer to the first research question is described in the Theoretical Framework.

3.3.4 RQ2 Detection of sandbars
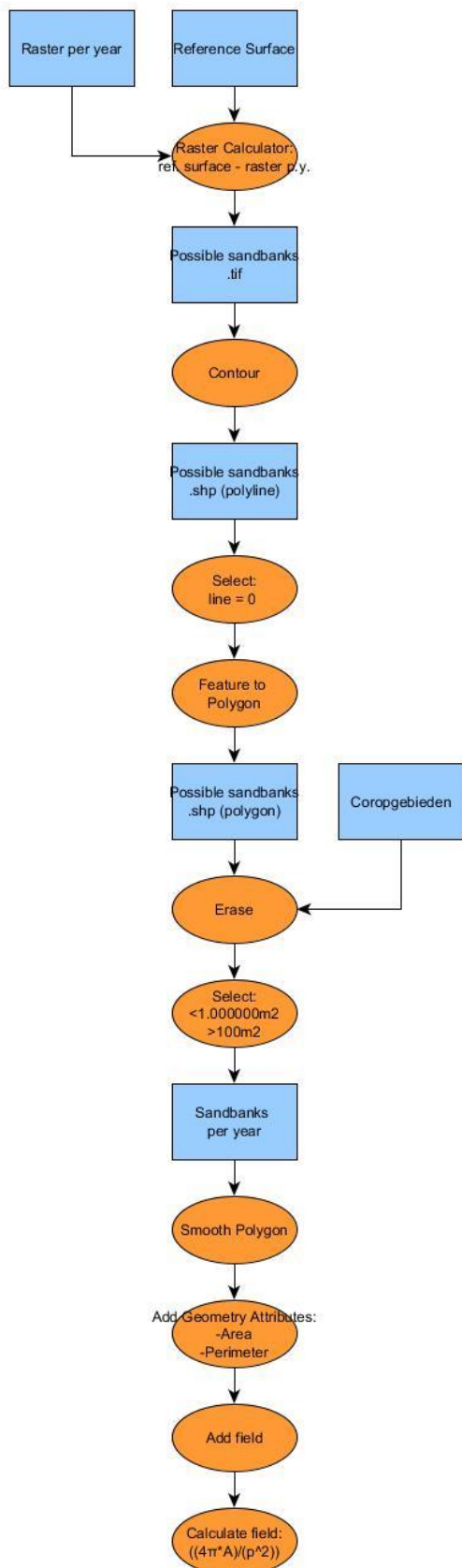
Figure 13: Methods used to detect sandbars

The second step is based on a literature review and data analysis. The first part of this step is based on a literature review that has been done by searching for techniques of sandbar detection.

In this study, the detection of sandbars has been done with a reference surface. In figure 13 the overall workflow to detect sandbars has been visualised with the usage of a reference surface.

The first step is to use the raster calculator to calculate the possible sandbars. In this tool the expression: 'reference surface – raster per year' has been used. It calculates for every year the difference between the same pixel of in the reference dataset and the dataset with the actual height values. When the difference is a positive number it means that the actual height data is higher than that of the reference surface and thus a possible sandbar is detected.

Further, in the analysis, the shape of the sandbar is of importance. Working with a raster when analysing shapes is not efficient so the raster dataset must be changed into a valuable shapefile. To do so the tool 'contour' has been used. This tool makes isolines of the raster dataset. The next step is to select all the lines with the value 0 because those are the intersections of the two raster datasets and thus depending on the form of the detected sandbars. Those lines are directly saved as polygons with the 'feature to polygon' tool.

Then, there are some conditions for the detected sandbars. The first one is to erase the sandbars detected on the coast. Because this is not possible, they need to be removed from the dataset. With the 'erase' tool and with a dataset of the Dutch coast (Coropgebieden), those sandbars were removed. Another condition is that the sandbars need to be smaller than 1.000.000 m2 and bigger than 100 m2. These numbers were chosen to remove really small or big features that are not likely to be a sandbar. After those conditions were followed, a shapefile with sandbars per year resulted.

To further analyse the shape of the sandbars the Polsby-Popper (PP) Test is performed. Before the test can be performed the data must be modified. First, the polygons must be smoothened. Smoothing will avoid fractal effects that can occur when analysing with polygon data retrieved from raster data, as in this case. Smoothing will be done through PAEK smoothing. PAEK is an acronym for Polynomial Approximation with Exponential Kernel. It calculates a smoothed polygon using a parametric continuous averaging technique (Esri, n.d.-a). The current point coordinates are calculated by the weighted averaging o the coordinates of all points of the source line. The weights of each point decrease with the distance along the line to the current point.

Then the perimeter and area of each polygon must be calculated as the input of the PP test. These attributes are calculated with the 'Add Geometry Attributes' tool. A new field can be made where the tool 'calculate field' can calculate the PP value.

The PP-test measures the compactness of a shape. It gives a mathematical insight into the relationship between a shape's area and perimeter. The test is defined as the ratio of the area of a shape to the area of a circle (the reference shape) that has the same perimeter as the shape (Fan, Li, Wolf, & Myint, 2015). The equitation is as followed:

$$PP = \frac{4\pi A}{p^2}$$

The *A* in the equitation is the area of the polygon and the *p* the perimeter of the polygon. The equitation result in a value between 0 and 1 per polygon. A value closer by 1 indicates a compact polygon while a value closer to zero an elongated polygon.

3.3.5 RQ3 Detection of cycles
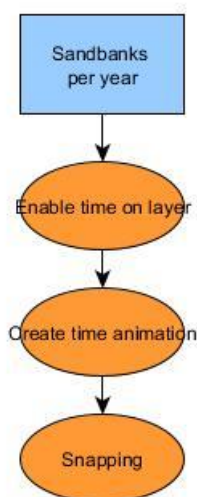
Figure 14: Workflow of sandbar pattern detection

The method that is used in this research to detect cycles of sandbar movement is 'snapping'. This is a method whereby different moments of time can be set to form a timeline. The detection can be done visually because it is known how sandbars move over time.

To generate a time series, firstly time must be enabled on each layer that needs to be in the time series. This can be done per layer by the properties of the layer. Then, with the 'animation' tool, the option 'create time animation' can be used to create a time series. After this, the snapping method was used to analyse the created time series.

When looking at cycles, different kind of cycles can be detected. First a cycle related to the shape of the sandbar itself. This can change over time. Besides this, also the change of location can be analysed with the snapping tool. So, both changes of cycles can be analysed with the usage of the snapping method. The steps that must be taken are shown in figure 14.

3.3.6 RQ 4 Validity analysis

Outcomes of analysis are just outcomes. There is always are an inherent tendency to trust the results of computer models. Because outcomes cannot be assumed to be always right, there must be a kind of check if the results can be validated or not. This can be done for example to compare the outcomes with literature or other researches that have been done related to the subject. To see if the outcomes of this research are reliable, the comparison of the outcomes with literature will be done. Different researches are done in this field. For example the thesis of Arno Timmer (2017). He wrote his thesis about the migration and characteristics of nearshore sandbars. The basis of his research have some similarities with this research, especially related to the analysis part. Besides this, he also chose the Netherlands as his case study. This means that the outcomes of this research can easily be checked with his outcomes.

Other reports related to the methods used in this research will be looked at to see the differences in possible outcomes. This could be quite of a challenge because not much has been written especially about the methodology of how to detect the shape of sandbars.

The reference surface created for this research is also an interesting point related to the validity of the research. Therefore, a sensitivity analysis will be conducted to see if the reference surface will have a significant impact on the results, specifically on the number of sandbars that are detected. A sensitivity analysis tests a model's response to changes in its parameters and assumptions (Longley et al., 2011). In this research, it means that the reference surface of 1994 will be adjusted with the values of other years. It is not possible to do this for all the 54 years of data because of time constraints. Therefore, specific moments in time are chosen: 1975 and 2009. This means that a reference surface will be made with data before 1994 and one after 1994. The creation of those reference surfaces will be done in the same way as the reference surface of 1994. A new analysis will be done with those two reference surface and the results will be compared to the results of 1994. After this comparison, a conclusion can be given about the sensitivity of the reference surface. If the results of the reference surfaces of 1975 and 2009 differ from the results obtained with the reference surface of 1994, it could be said that the reference surface used has an impact on the results and therefore must be wisely chosen. Also, an independent t-test is performed to see if the means of the number of sandbars are significantly different from each other.

Besides the validity of the reference surface created, the smoothing of the polygons that represent the sandbars is also interesting to analyse further. To change the smoothing technique, the sensitivity of smoothing can be investigated, which will tell if the shape of sandbars is dependent on which smoothing technique has been used. Besides the PAEK smoothing that has been used in the original analysis, non-smoothing and Bezier-interpolation will be tested on the same data. The difference between both smoothing techniques is that the Bezier-interpolation technique uses a subset of existing vertices to fit the curves it creates (Planetary Mappers Meeting, 2012). Another difference can be found in the output of the techniques. When using PAEK smoothing, the user can choose a tolerance level. This means that the user can choose the length between vertices. When entering a higher tolerance, the length between vertices became bigger which results in less preserved detail. While entering a lower tolerance results in less length between vertices and therefore more preserved detail. When using Bezier interpolation as smoothing techniques, no tolerance can be chosen which will result in less original detail preserved (Planetary Mappers Meeting, 2012). Figure 15 shows the difference in the use of existing vertices which Bezier interpolation uses. The PAEK smoothing techniques do not use the original vertices.
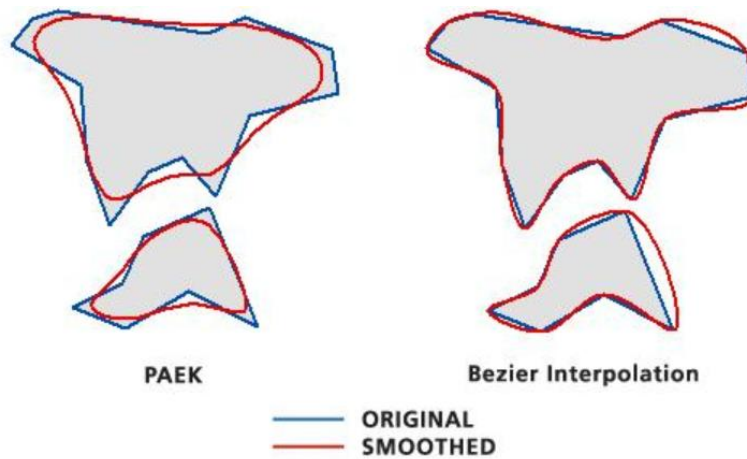
Figure 15: PAEK and Bezier smoothing techniques (Esri, n.d.-b)*.*

3.4 Software

To perform the analysis explained before, software is needed. The software used in this project is based on the usage of geographical data. Most analyses were done in the software package ArcGIS from ESRI. Within this software package, the program ArcMap can be used to analyse geographical data. Most of the analysis was executed using model builder. Within model builder, a model can be made consisting of different steps or methods that will shape the data. This is useful because such a model can be used on more than one dataset. Also, it gives a great overview of the steps that must be taken to come to the end result.

Besides the analysis, visualisation can also be done in ArcMap. Besides ArcMap, ArcGIS Pro has been used for time series animation because this program can easier work with time series related to ArcMap.

Other programmes used in this research are Python and Enthought Canopy. Those programmes are used for writing Python scripts for the pre-processing of the data.

4. Results

In this chapter, the results of the performed analysis will be explained. Before the real analysis, a reference surface has been made to identify the sandbars. The results of the reference surface will be explained in paragraph 4.1.

Paragraph 4.2 elaborates on the identification of sandbars. In this paragraph, some general information about the identification of sandbars will be explained, such as the number of detected sandbars per year and per coastal area.

Paragraph 4.3 dives into the shapes of the detected sandbars. In this paragraph, the scores of the PP-test will be discussed even as examples of different detected shapes of sandbars.

The next paragraph (4.4) discusses the change over time. This paragraph is split into two sub-paragraphs. The first subparagraph is about the change over time-related to the location of the sandbar. Different examples of movements are visualised in this subparagraph. Besides the change of location, the change of shape of the sandbar is also explained, in subparagraph 4.4.2. In this subparagraph, the change of the shape of the sandbar will be discussed with examples related to its surface and PP-value.

Besides the overview of the results in this chapter, the discussion of the results is also represented in this chapter. An overview of the discussion of the results can be found in chapter 7.

4.1 Reference Surface

As said in chapter 3, the detection of sandbars will be done with a reference surface. A slope analysis is executed to see if the created reference surface has a continuous slope. When exploring the created reference surface it can be said that the slope of the pixels lies between 1% and 5%. When looking at the exact number almost 92% of the values lie between 0 and 1 %. Just 0.48% of the pixels have a slope of 5% or more as can be seen in table 2.

Table 2: Slope of the reference surface

Slope percentage	% of pixels
0 - 5	99.52%
5 - 10	0.43%
10 – 15	0.05%
15 -20	0.00%
20-25	0.00%
25-30	0.00%
30-35	0.00%
35-40	0.00%
40-45	0.00%
45-50	0.00%

After running the analysis to detect the sandbars, the final polygons can be viewed. When looking at the possible sandbanks it could be said that the surface differs a lot. So the question which arises is, how much cubic meters represent the surface of a sandbank. Diving into literature, there is no clear answer. Most literature defined sandbars by their highest point instead of the shape of it. To filter the data, it is decided to exclude polygons with a surface under 100 square meters. Due to interpolation, there are values with a surface of more than 1 million square meters. Those values are outliers and thus must be removed from the data.

4.2 Detected sandbars

When examining the final data presented as sandbars at the Dutch coastal areas, it is interesting to see that there are places over time where many sandbars are detected and also places where fewer sandbars are detected. Figure 16 is an overview of the number of sandbars detected per coastal area between 1965 and 2018. This figure shows two coastal areas where no sandbars are detected: KV1 and Maasvlakte. This is due to the fact that the data of those two coastal areas are not present in the analysed data. Furthermore, it can be stated that most sandbars can be found near the coastal area of Noord-Holland. It could be due to the size of the coastal area, Noord-Holland is one of the biggest coastal areas of the Dutch coast. The coastal area where the second most sandbars are detected is Terschelling. Terschelling is one of the islands in the north of the Netherlands.

In general, it could be said that more sandbars are found around the Dutch islands (Schiermonnikoog, Ameland, Terschelling, Vlieland and Texel) compared to the rest of the Netherlands. At Noord-Beveland only 281 sandbars are found. Just like Noord-Holland, this is due to the size of the coastal area. Noord-Beveland is the smallest coastal area of the Netherlands. Overall there are 21.164 sandbars detected near the Dutch coastal areas.
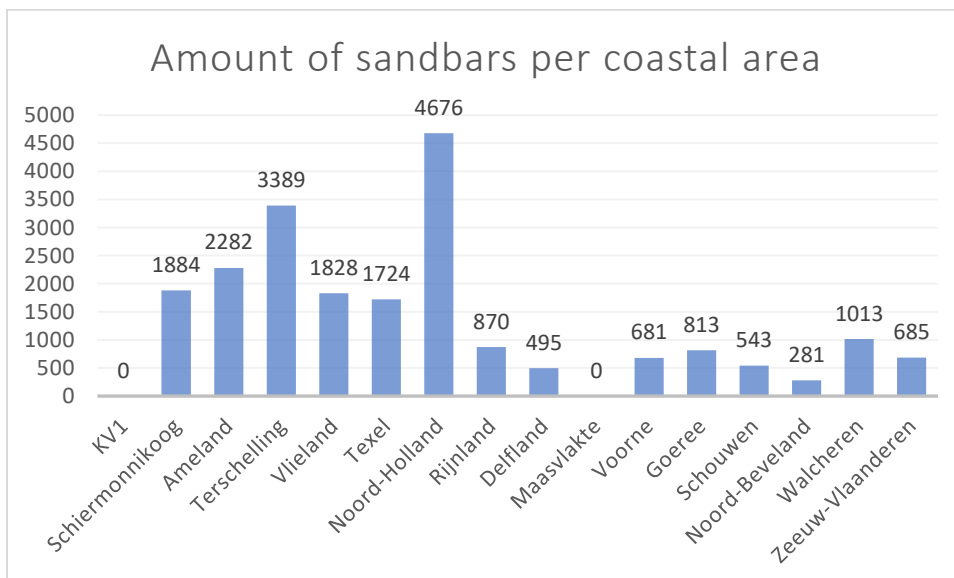
Figure 16: Detected sandbars at the Dutch coastal areas per coastal area
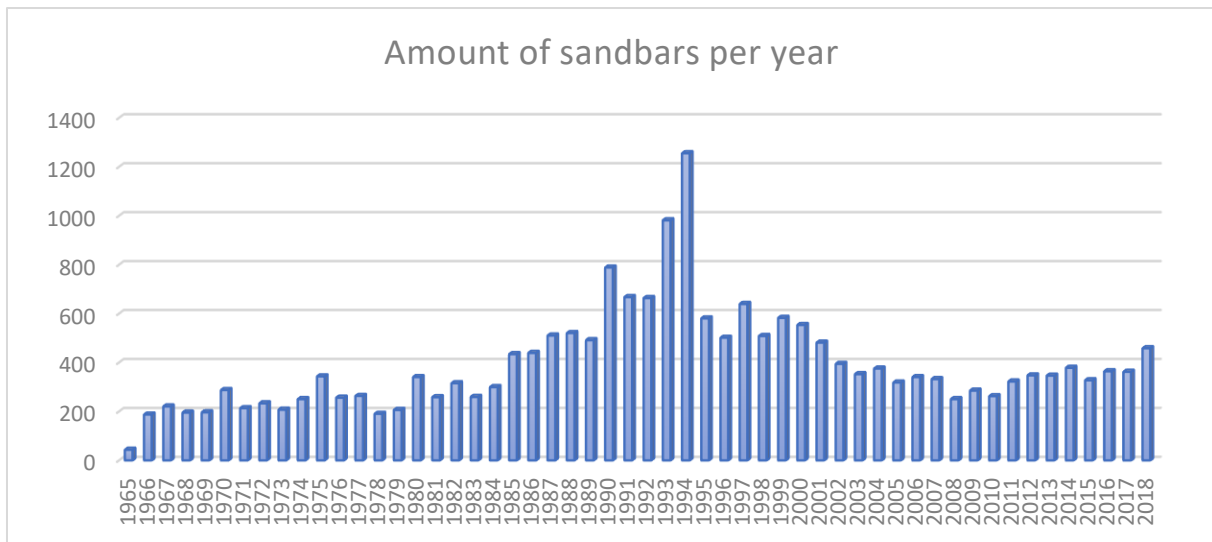
Figure 17: Detected sandbars at the Dutch coastal areas per year

An interesting point can be made when analysing the number of detected sandbars. Figure 17 shows the detected sandbars per year. It shows that in 1965 the least number of sandbars are detected in the data, there were only 43 sandbars detected. This could be due to the fact that in 1965, data collection was in an early stage which resulted in less accurate data collected. Besides this, there could be other reasons why this year only 43 sandbars where detected. Between 1966 and 1984 the number of sandbars detected in the data where similar. From 1985 till 1994, more and more sandbars were detected in the data. In the data of 1993 and 1994, the biggest numbers of sandbars are found. This could be due to the reference surface made to detect sandbars. For this reference surface, data of 1994 is used. Only the deepest points are used for the reference surface. So, if the deepest measurement per transect differs significantly, the comparison of the data related to the reference surface is affected by this decision. This will be further explored in chapter 5.

4.3 Shape

The shape of the detected sandbars is analysed with the PP test. Figure 13 gives an insight into the smoothened dataset of the test. The score on the PP test can be seen of each year. The closer the score to 1, the more circular the sandbar is while a score closer to 0 the shape of the sandbar is elongated.

In figure 18 it can be seen that there are no outliers visible in one of the used datasets. The minimum and maximum values are ranged around 0 and 1 in all datasets, which indicates that all datasets have an almost circular polygon (value closed at 1) and also a flattened out polygon (value closed to 0). The value 0 and 1 are not present in any dataset, this because there could be no perfect circle or a straight line. The median of all datasets lies between 0.35 and 0.5. There is one boxplot that differs from the rest. This boxplot is from 2018. Where the medians of all the datasets are quite similar to the median of the 2018 dataset is approximately 0.65. This means that the dataset of 2018 has more circular formed sandbars than the datasets of all the other years. The other years have more elongated forms of sandbars.
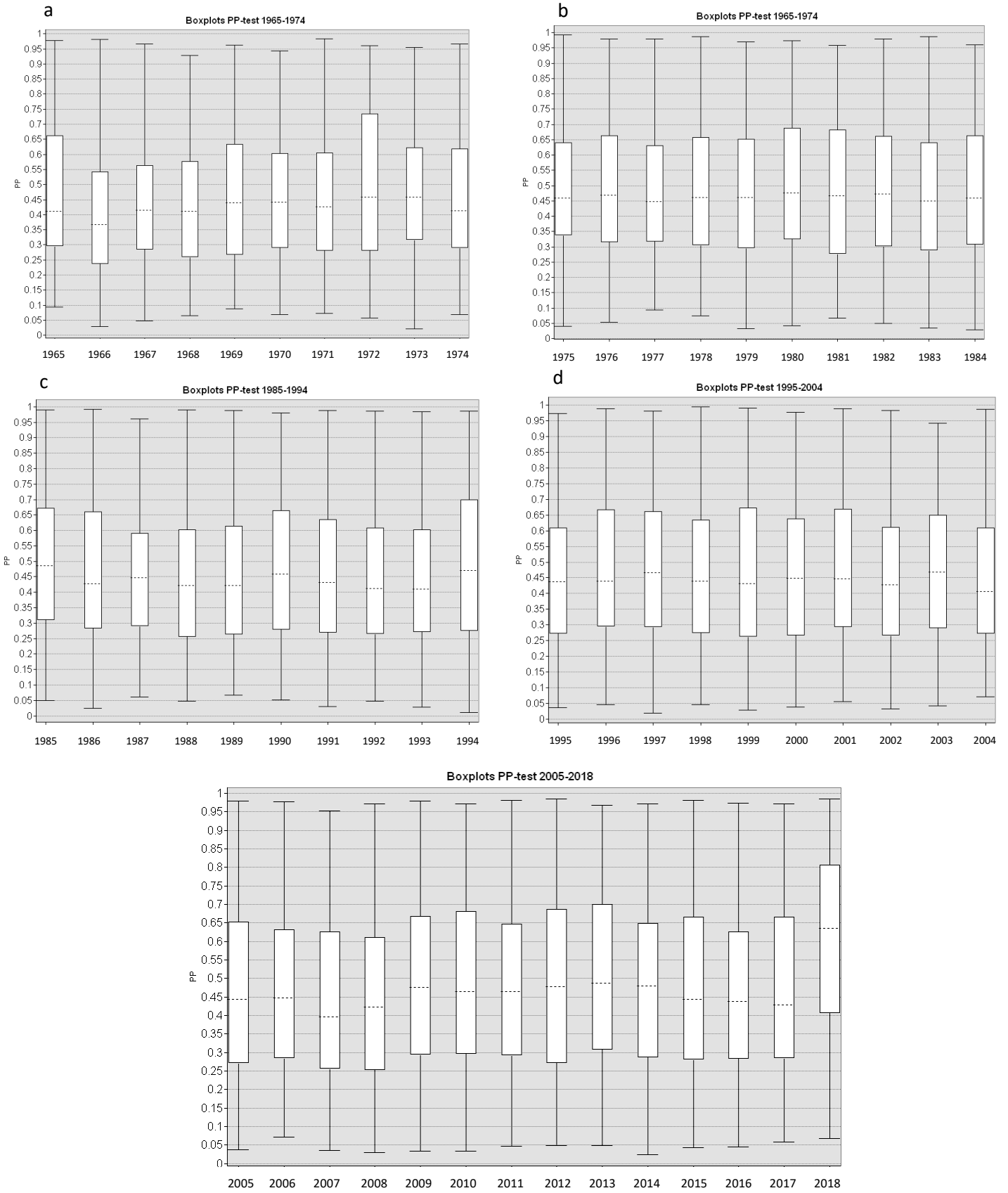
Figure 18: Boxplot of the Polsby-Popper test per 10 years: a) 1965-1974, b) 1975-1984, c) 1985-1994, d) 1995-2004 and e) 2005-2018

Visually, the shapes of the sandbars differs a lot. As seen in figure 19a, there are long sandbars that are almost parallel situated related to the coast (the grey area). There are also little long stretched sandbars more shore of wards. The PP values of these polygons differ between 0.04 and 0.3, which indicates the long stretched sandbars as seen in the figure. One sandbar, the second smallest polygons close to the coastline has a PP value of 0.8. In the figure, this polygon is more compact and rounder than the ones further from the coast.

Also, other forms of sandbars appear as can be seen in figure 19. Figure 19b indicates more rectangle sandbars. This form of sandbars can be related to the form of the coastal area, in this case, the coastal zone at the province Zeeland, which is not a straight line. The PP values of those sandbars vary between 0.58 and 0.64. This is an average value which indicates that the polygons are not round and compact but also not elongated.

At the islands in the north of the Netherlands mostly small elongated sandbars appear as seen in figure 19c. Most of the sandbars seen in these figures have a PP value between 0.21 and 0.36 which indicates elongated sandbars. Some smaller sandbars have higher PP values which indicate a rounded and compact shape. This is hard to see on the figure because those sandbars are relatively small.
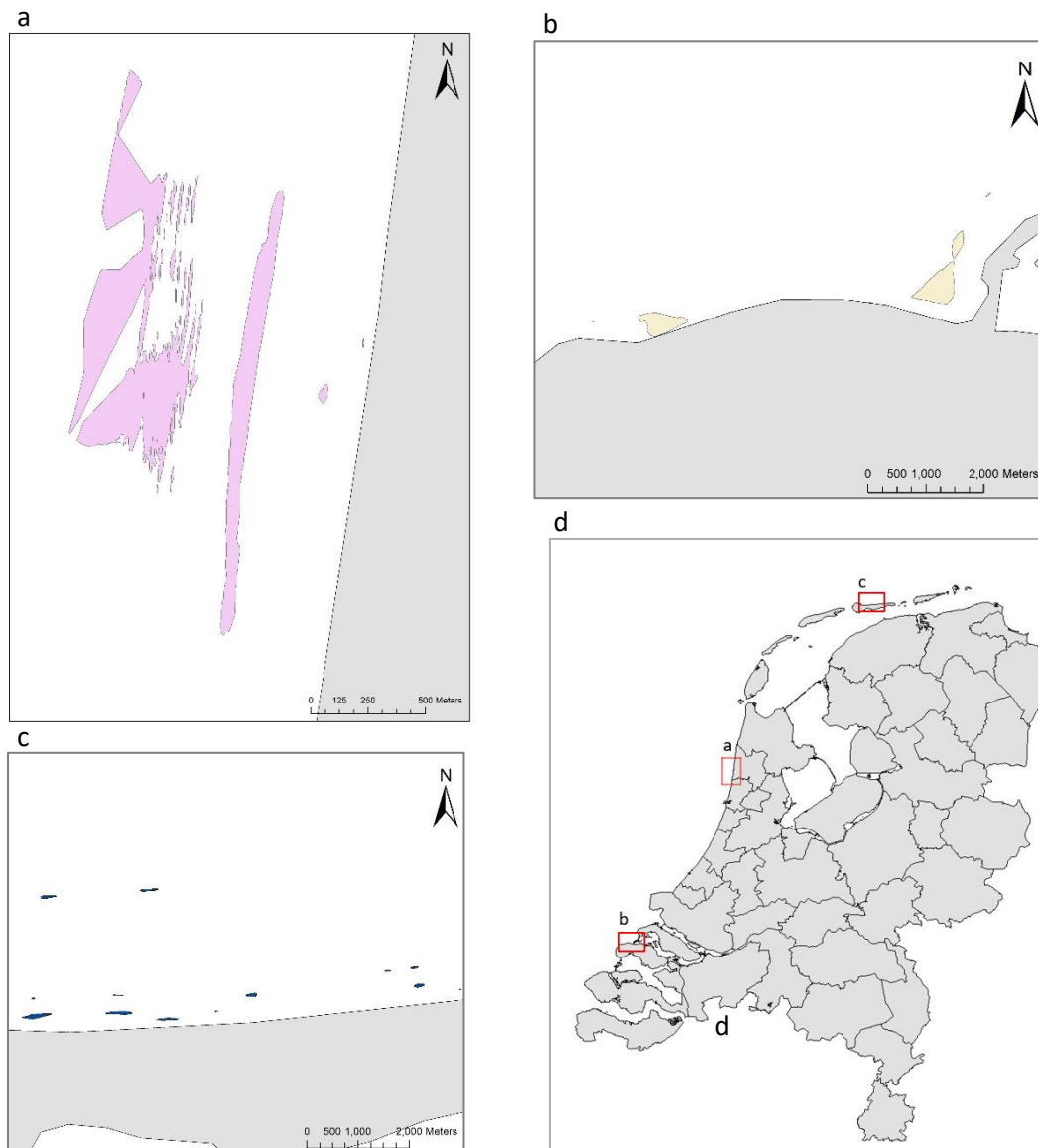
Figure 19: Different sandbars near the Dutch coast: a) 1991, b) 2011, c) 1970 and d) reference of the locations

Figure 20: Sandbars at the coast of Noord Holland, 2005

There are sandbars visible that have similarities with the literature found of their shape. An example can be seen in figure 20. With the black line, the form of the sandbar is highlighted and relating to literature this sandbar has a crescentic form (see paragraph 2.1). Besides the typical form, this sandbar is also almost parallel situated near the Dutch coastal area.

4.4 Change over time

4.4.1 Place

To indicate how the sandbars move over time, a time series has been made ArcMap. The time series created to give some great insight into the movement of individual sandbars. Some clear movement patterns became visible.
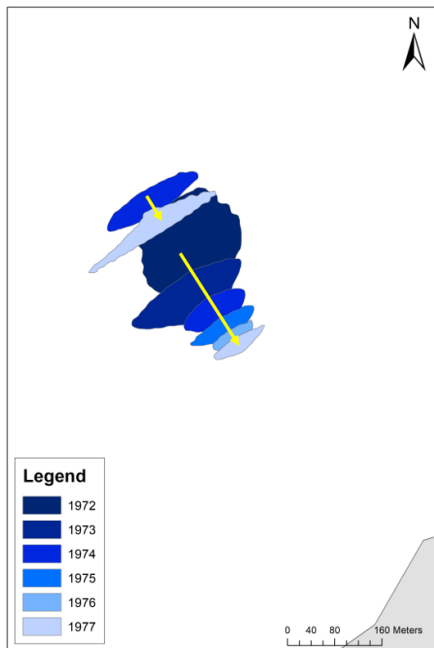
Figure 21: Movement of sandbanks near the coast of Zeeland

For example, when looking at figure 21 the movement of a sandbar is visualised. The sandbar suddenly pops up in 1972 as a round feature as seen in orange. The next year, in 1973, the sandbar moves towards to coast, visualised by the grey area. From 1974 till 1977 this movement towards to coast is visible. The movement stops in 1977 and in 1978 no sandbar is visible anymore. The distance of movement of this particular sandbar is around 200 meters towards the coast. This means that the sandbar moved with an average of 33 meters per year. Besides this movement over 5 years, another movement takes place as can be seen by the short arrow which starts in the green outer polygon in 1974. It is not clear if this is a movement of a bar, or a new bar appears in 1977. Between those years, no sandbar can be detected near the two bars. Thus it is possible that the two sandbars furthest away from the coast do not have a relation
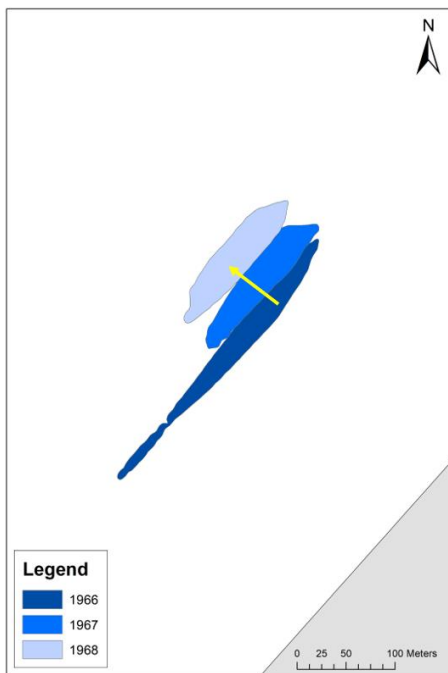
Figure 22: Movements of sandbars near the coast of Zuid Holland

There are also examples where the movement of sandbars do match the literature research of sandbar movements. Figure 22 is such an example of the movement described in the literature. The figure shows the movement of one sandbar from 1966 to 1968. The sandbar in 1966 appears around 234 meters away from the coastline. In 1967 the sandbar moved more than 30 meters, away from the coast. This also happened with the movement of the sandbar between 1967 and 1968. Before the sandbar disappears somewhere in 1968 or 1969 before the measurement in 1969 the sandbar moved 60 meters over two years time. In literature, the movement of sandbars is described as movements away from the coastline. Through this example, the literature of sandbar movement is confirmed when looking at this particular movement.

Besides the movement of the sandbar, a change in shape can be observed: it changes from a wide elongated shape near the beach to a smaller shape in the deeper shoreface.
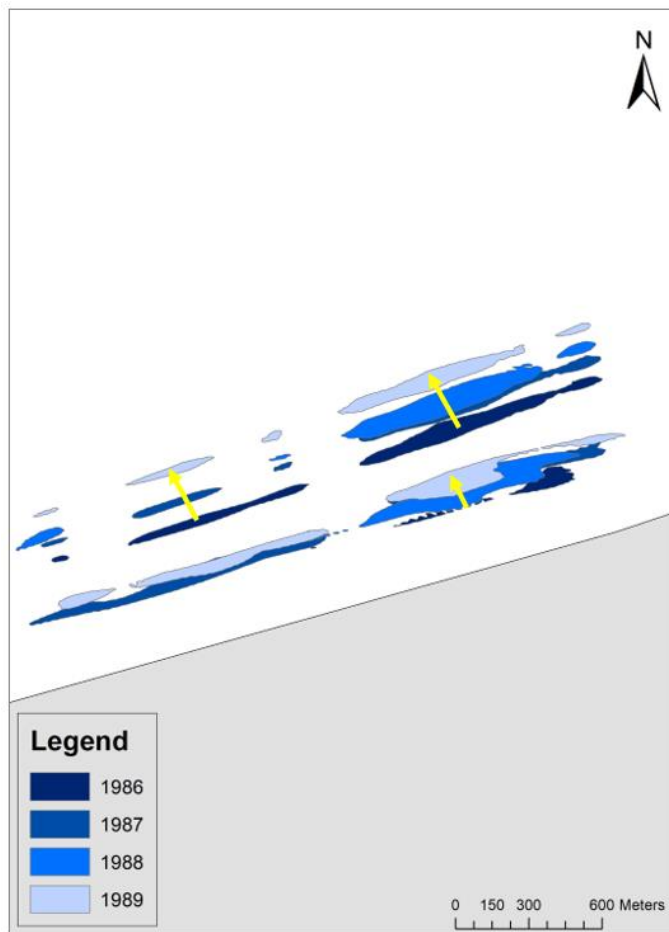
Figure 23: Sandbar movement from 1986 till 1989 at Terschelling

Earlier research (Ruessink et al., 2013) mentioned the appearance of the two-bar system. In figure 23 such a system where two sandbars are visible parallel to each other and the coastline is visible. Visually it could be said that the sandbars monitored are the same sandbars over time. Ruessink (2013) also mentioned that the inner bar, the one closest to the coastline is remarkably smaller than the outer bar. The sandbar found in the data does not suit this description. As can be seen, the inner bars are almost the same size as the outer bars. Remarkably, the bars on the left of the map differs from the theory. Here the outer bars are smaller than the inner bars over the years.

The movement of the inner and outer bars are different. The inner bar does not move much between 1986 and 1989 but is in all the years present. In 1986 the bar appeared at approximately 270 meters of the coastal area. In 1989 the closest point related to the coastal area is around 340 meters. This means that in 4 years the bar moved 70 meters, which is an average 17,5 meters per year. The outer bar moved more than the inner bar. It appeared around 570 meters of the coastal area in 1986. In 1989 the sandbar is located at 800 meters away from the coastal area. This means that in 4 years the sandbar moved 230 meters, which is an average of 57,5 meters per year. The outer bar moved 40 meters per year more than the inner bar, which is a major difference.

Besides examples where sandbars move one way, towards the coastline or away from it, there are also sandbars visualised that firstly moved towards the coastal area for some years and then suddenly moved away from the coastal area. This movement is not named in literature and therefore a new addition to the way of sandbar movement. To visualise this movement, the centroids of the sandbars are used because visualising the actual sandbar is not possible because of overlapping.

An example of this movement can be seen in figure 24. In this figure, the yellow starting point is 1967, as seen in the left upper corner of the figure. The real coastline is not visible, because the movement takes place further away from the coastline around 650 meters. Therefore a representative coastline has been drawn to see the movement of the sandbar in perspective. The first year, the bar moves to the coastline. The second year it moves away from the coastline, followed by two years where the sandbar is moving back. The year after, the sandbar moves again away from the coastline. In the last three years, it can be seen that the sandbar is moving towards to coastline and the movement stops in 1975.

This sandbar movement is more complex than the ones visualised before. There are different external factors that may influence movement and thus can create this complex movement. One of those factors can be the impact of the waves which is related to weather conditions.
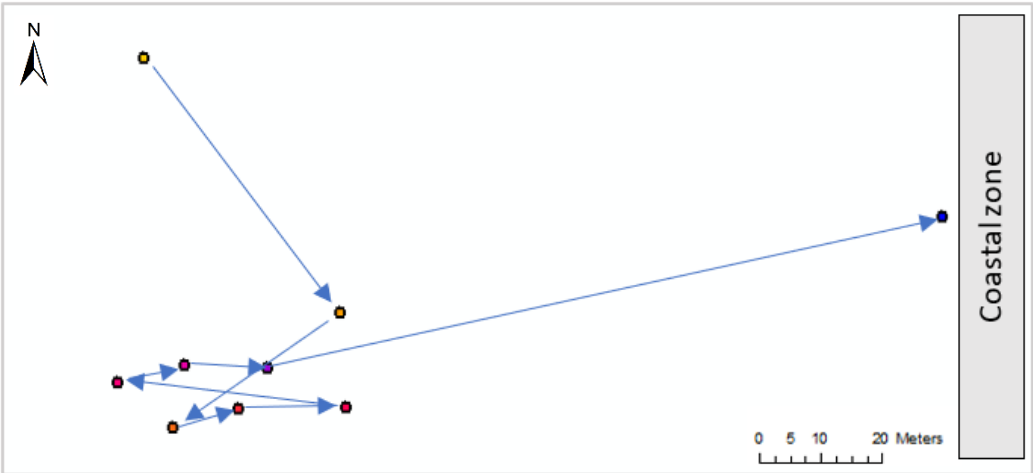
Figure 24: Centroids representing the sandbar movement from 1967 till 1975

The last movement which can be visualised through data analysis is a situation where the sandbar almost does not move at all. Figure 25 is an example of a sandbar that did not move a lot. Especially the first three years, the centroids of the sandbar moved approximately 7 meters per year. The movements distance following these three years increased. Besides the movement of the centroids related to each other, the movement towards or away from the coastline is also interesting in this case. The centroid of 1966 is the furthest away from the coastline, around 58 meters. The point closest to the coastline is 1971 with a distance of 33 meters. This means that from 1966 till 1974, the sandbar moved between a band of 25 meters towards and away from the coastline.
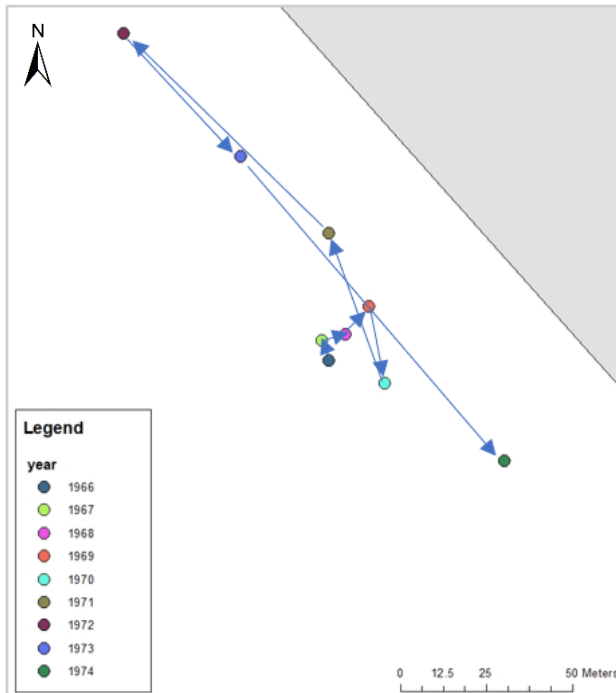
Figure 25: Single sandbar movement from 1966 till 1974 visualised by centroids

4.4.2 Shape

Besides the movement of sandbars over time, the shape of the sandbar also changes over time. In theory, a sandbar first appears at a small size and grow over time. On a particular moment in time, the sandbar will decrease in size. In the end, no visible sandbar will be left. On the data, different kind of shape change can be detected. First of all, a pattern is visible where the sandbar appeared and over time decrease in shape. This is shown in figure 26. The change in the shape of a sandbar is shown.

In figure 26a the change of the shape has been visualised. In this figure, it can be seen that in 1969 the sandbar was the biggest compared to 1970 and 1971. In 1970 the rough edges at the north and south of the sandbar disappeared and in 1971 the sandbar is only a small line. The numbers related to this change indicates that the size of the sandbar decreased fast over the three years. In 1969 the sandbar was almost 60.000 m2. The next year the sandbar has decreased in size to just approximately 33.000 m2. This means a decrease of almost 45%. In 1971 the surface decreased again to approximately 5.000 m2. In the end, in 1971 just 10% of the total surface remained. It can be said that there is a clear decrease in the surface over time.

Looking at the PP test, the roundness of this sandbar also change over time. As said, the change between 1969 to 1970 is mostly seen at the North and South side of the sandbar (figure26a). Figure 26b supports this visual change. The higher the PP index, the more round the shape is. When the index is closer to zero, the shape is more elongated. In 1969 the PP index was 0.63. This means not a round or elongated shape as seen in figure 21a. In 1970 the number increased to 0.83. It is clearly visible that the sandbar became more round. In 1971 the index number decreased to 0.36 and the shape is elongated.
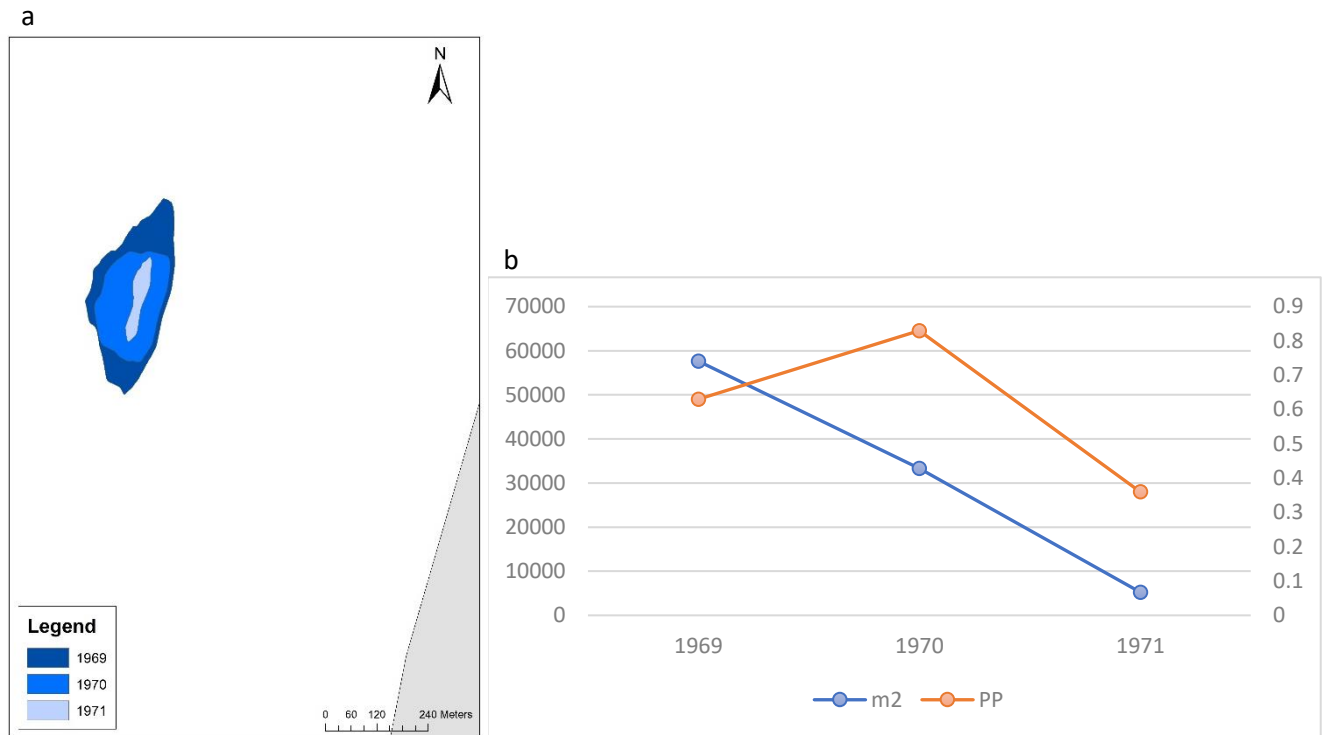
Figure 26: Change of shape of a sandbar from 1969 till 1971: a) visual change, b) change in numbers

Another, quite similar example can be seen in figure 27. In this example, a sandbar change from 2013 till 2016 is visualised. The visual change between 2013 and 2014 in figure 27a is minor. The shape itself did not change much, only the sandbar is smaller. The North-East side of the sandbar changed the most. The visual change between 2014 and 2015 is major. The shape of the sandbar changed from an elongated form to a crescentic form. This crescentic form is also visible in the data of 2016. It is likely to say that this is the same sandbar because of the place, and in its surrounding there are no other sandbars. Only the form of the first half of the timeframe and the second half of the timeframe differs a lot.

Besides the visual change figure 27b gives the change in number. The surface of the sandbar decreased from 2013 til 2015 in a straight line: in 2013 the surface was approximately 10.000 m2, in 2014 the surface was 5.300 m2 and in 2015 it was 350 m2. Between 2013 and 2014 the surface was almost halved in size when looking at figure 22a, it is not really visible. Between 2014 and 2015 the surface further decreased by more than 90%. From 2015 to 2016 the surface stayed almost the same.

The PP index shows a change in form from round to elongated. Especially in the first three years: the index number decreased from 0.5 to 0.4 and then to 0.2. Between 2015 and 2016 there is a slight increase in the index: from 0.2 to 0.23. These numbers are almost similar.

As already been said, this example shows a change of shape of a sandbar in two different stages: the first half from 2013 to 2014, to a drastic change related to the 2015 data. The data from 2015 and 2016 is the second part of the change.

a

b
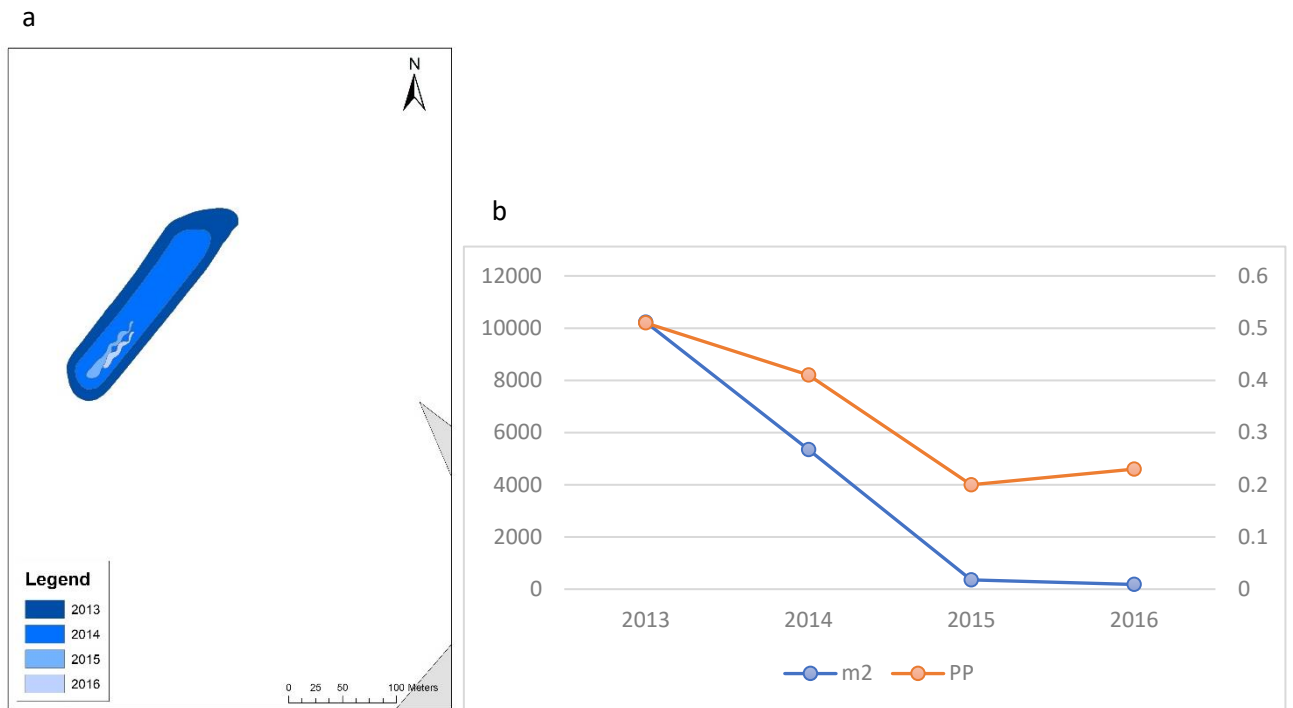
Figure 27: Change of shape of a sandbar from 2013 till 2016: a) visual change, b) change in numbers

There are also some other interesting changes in sandbars. Figure 28 gives an example with a gap in the data. In 1998 there was no sandbar detected in the same area. While in 1999 and 2000, there was a sandbar detected. It is questionable if the sandbar in 1999 and 2000 is the same sandbar as the one from 1991 till 1997, or it is a new one. Because nothing was detected in 1998 it is likely to say that this is a new sandbar on the same spot.

The sandbar formed in 1991 started as a small sandbar with a surface of approximately 2.500 m2. From 1991 till 1995, the surface of the sandbar increased. After 1995, the surface decreased and the sandbar vanished in 1997. This is a typical example of the change of the surface of a sandbar: firstly an increase of surface until a specific point in time, followed by a decrease of the surface.

The PP index shows an interesting connection to the surface of this sandbar. From 1991 till 1995, an increase of the index number is visible in figure 28: from 0,25 to 0,51. This means that the shape of the sandbar changed from a more elongated form to a rounder form, but still not perfectly round. The number 0,51 indicates that the form is nor elongated, nor round. After 1995, the shape of the sandbar is slightly changing to a more elongated form: the index number changed from 0.51 to 0.44. Besides this, the data from 1999 and 2000 gives the same kind of relation. In 1999 the surface of the sandbar is bigger than in 2000. In 1999 the number of the PP index is also bigger than the one in 2000.
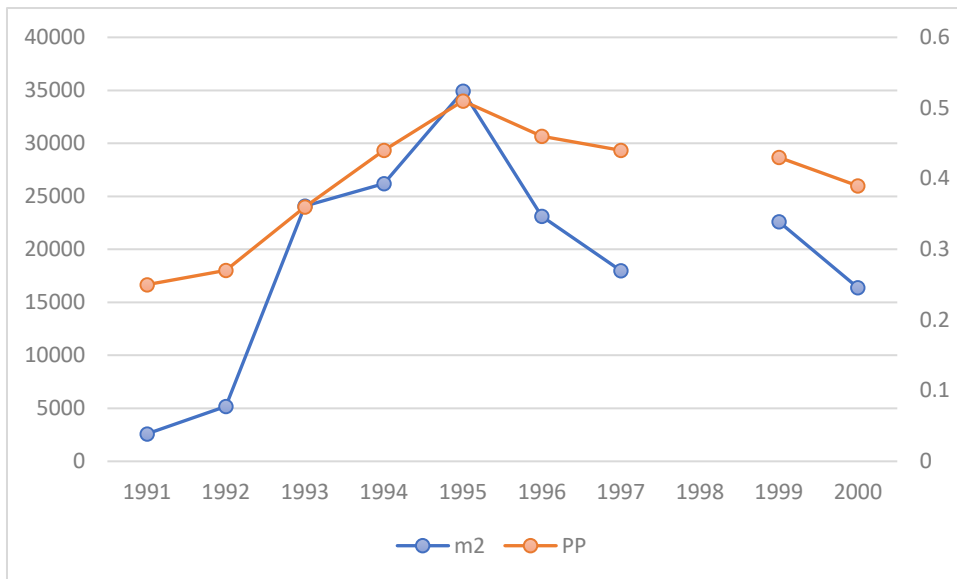
Figure 28: Change of a sandbar from 1991 till 2000
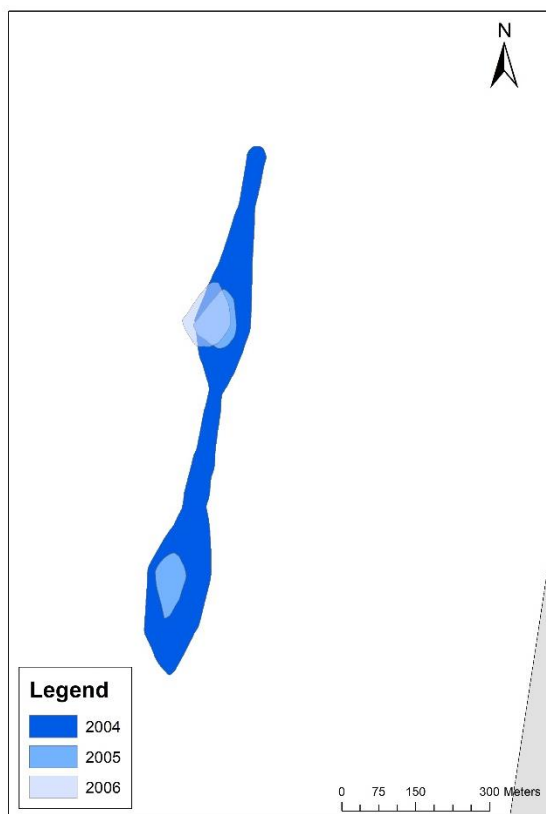
Figure 29: Typical change of sandbar shape, 2004-2006

A visible example of a change of shape of a sandbar that is frequently detected is shown in figure 29. The figure shows a part of the change of a sandbar shape pattern. The total sandbar pattern is visible from 1990 till 2006. The figure shows the last stage of the sandbar. In 2004 there is still one elongated sandbar visible parallel to the coastal area (as seen in grey). It can be seen that this sandbar have two thicker and rounder areas with in between a more elongated area. There is also an elongated area visible at the most northern point of the sandbar. In 2005 this shape is not visible anymore. The one sandbar is divided into two separate rounder sandbars. The shape of the two rounder sandbars in 2005 match the shapes of the rounders parts of the sandbar in 2004. When the data of 2006 is added to the timeframe, just one sandbar remained. The sandbar at the south part of the figure vanishes, while the one in the north remained almost in the same shape as it was in 2005. As already been said, this kind of pattern is visible not only at this sandbar. There are multiple sandbars detected with this change.

5. Validity

In this chapter, the results of a sensitivity analysis are presented. The sensitivity analysis consists of two parts: change in reference surface and change in smoothing polygons.

First, the change of the reference surface is discussed. An overview of the general results when using the reference surface with data of 1975 is explained in chapter 5.1. Within this paragraph general results are discussed even as the shapes of the detected sandbars.

In chapter 5.2 the results related to the use of the reference surface with data of 2009 is explained. In this paragraph, the general results are discussed even as the shapes of the detected sandbars.

Chapter 5.3 compares the results of the three different analysis with each other. This is done with some statistical tests.

The last paragraph, 5.4, is about the other part of the sensitivity analysis. In this paragraph two different smoothing techniques are compared: Bezier interpolation and PAEK smoothing.

5.1 Reference surface 1975

A reference surface of the 1975 data has been made to see if the results differ when using another reference surface. First, when looking at the reference surface itself it could be said that the slope of most pixels in the reference surface lies between the 0 and 5% (see table 3). This means that there is an almost constant slope is generated. Around 99,8% of the pixels have a slope between 0 and 5% while just 0,2% of the pixels have a slope of 5 till 10%.

Table 3: Percentage pixels with a certain slope in the reference surface of 1975

Slope percentage	% of pixels
0-5	99,81%
5-10	0,16%
10-15	0,01%
15-20	0,00%
20-25	0,00%
25-30	0,00%

When examining the data generated with the 1975 reference surface, it is interesting to see that there are places over time where many sandbars are detected and also places where fewer sandbars are detected. Figure 30 is an overview of the number of sandbars detected per coastal area with the 1975 reference surface. This figure shows two coastal areas where no sandbars are detected: KV1 and Maasvlakte. This is due to the fact that the data of those two coastal areas are not present in the analysed data. Furthermore, it can be stated that most sandbars can be found near the coastal area of Noord-Holland. It could be due to the size of the coastal area, Noord-Holland is one of the biggest coastal areas of the Dutch coast. The coastal area where the second most sandbars are detected is Ameland. Ameland is one of the islands in the north of the Netherlands.

In general, it could be said that more sandbars are found around the Dutch islands (Schiermonnikoog, Ameland, Terschelling, Vlieland and Texel) compared to the rest of the Netherlands. At Noord-Beveland only 186 sandbars are found. Just like Noord-Holland, this is due to the size of the coastal area. Noord-Beveland is the smallest coastal area of the Netherlands. Overall there are 25.802 sandbars detected near the Dutch coastal areas.
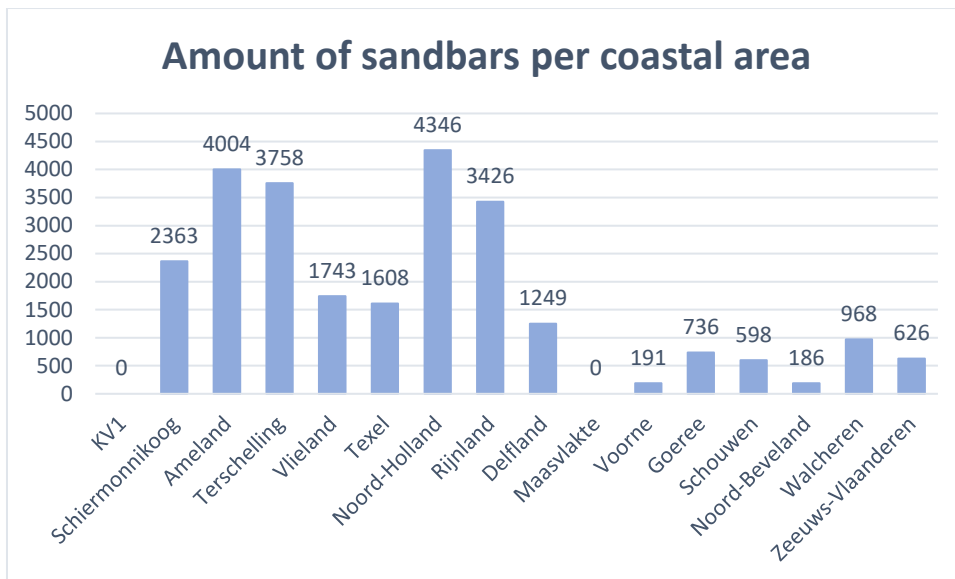
Figure 30: Detected sandbars at the Dutch coastal areas per coastal area (reference surface 1975)
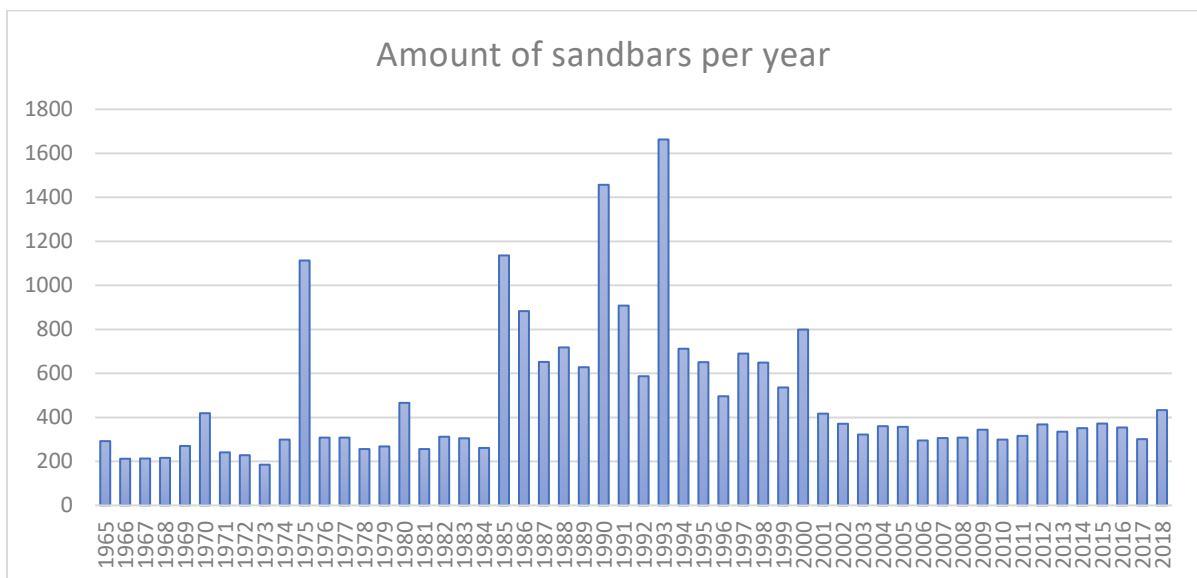
Figure 31: Detected sandbars at the Dutch coastal areas per year (reference surface 1975)

An interesting point can be made when analysing the number of detected sandbars. Figure 31 shows the detected sandbars per year when using the reference surface of 1975. It shows that in 1973 the least number of sandbars are detected in the data, there were only 185 sandbars detected. From 1965 till 1974 the amount of detected sandbars is lower than 400. This line continues until 1984. Only in 1975, it could be seen that many more sandbars are detected, namely 1113. This could be due to the fact that the reference surface used in this analysis is made from 1975 data. Therefore it could be said that it could be possible that the reference surface has a significant impact on the detection of sandbars. From 1985 till 2000, more sandbars can be detected than the previous years. Most sandbars are detected in 1993: 1663 sandbars were detected. After 1993 the number of detected sandbars decline and remains almost constant between 2001 and 2018.

5.1.1 Shape

The shape of the detected sandbars is analysed with the PP test. The boxplots related to the PP test with the reference surface of 1975 can be found in Appendix C. The score on the PP test can be seen of each year. The closer the score to 1, the more circular the sandbar is while a score closer to 0 the shape of the sandbar is elongated.

In the data generated with the reference surface of 1975, it can be seen that there are no outliers visible in one of the used datasets. The minimum and maximum values are ranged around 0 and 1 in all datasets, which indicates that all datasets have an almost circular polygon (value closed at 1) and also a flattened out polygon (value closed to 0). The value 0 and 1 are not present in any dataset, this because there could be no perfect circle or a straight line. The median of all datasets lies between 0.3 and 0.45. There is one boxplot that differs from the rest when looking at the median. This boxplot is from 2018. Where the medians of all the datasets are quite similar to the median of the 2018 dataset is approximately 0.55. This means that the dataset of 2018 has more circular formed sandbars than the datasets of all the other years. The other years have more elongated forms of sandbars.

Another interesting boxplot is the one from 1975. All the other boxplots have a quite small range of where the most values are situated. For example in 1973. The median of this year is around 0.4. Most of the values of this dataset lie between 0.25 and 0.55. Thus a range of 0.3. When looking at the data of 1975, the median of the boxplot is also around 0.4. The range of the values most occurred lies between 0.2 and almost 0.7. Thus a range of 0.5, which is a lot more than the example of 1973.

5.2 Reference surface 2009

A reference surface of the 2009 data has been made to see if the results differ when using another reference surface. Before a comparison can be made, some details about the reference surface will be explained.

First, when looking at the reference surface itself it could be said that the slope of most pixels in the reference surface lies between the 0 and 5% (as can be seen in table 4). This means that there is an almost constant slope is generated with the TIN-tool. Around 99,6% of the pixels have a slope between 0 and 5% while just roughly 0,3% of the pixels have a slope of 5 till 10%.

Table 4: Percentage pixels with a certain slope in the reference surface of 2009

Slope percentage	% of pixels
0-5	99,64%
5-10	0,27%
10-15	0,08%
15-20	0,01%
20-25	0,00%
25-30	0,00%

When examining the data generated with the 2009 reference surface, it is interesting to see that there are places over time where many sandbars are detected and also places where fewer sandbars are detected, just as the reference surface of 1975 and 1994. Figure 32 is an overview of the number of sandbars detected per coastal area with the 2009 reference surface. This figure shows two coastal areas where no sandbars are detected: KV1 and Maasvlakte. This is due to the fact that the data of those two coastal areas are not present in the analysed data. Furthermore, it can be stated that most

sandbars can be found near the coastal area of Noord-Holland. It could be due to the size of the coastal area, Noord-Holland is one of the biggest coastal areas of the Dutch coast. The coastal area where the second most sandbars are detected is Terschelling. Terschelling is one of the islands in the north of the Netherlands.

In general, it could be said that more sandbars are found around the Dutch islands (Schiermonnikoog, Ameland, Terschelling, Vlieland and Texel) compared to the rest of the Netherlands. At Delfland only 96 sandbars are found. When looking at the size of the area of Delfland, it is one of the bigger coastal areas. Therefore no clear explanation can be given related to the number of sandbars found and the size of the coastal area. Overall 9945 sandbars are detected on the Dutch coastal area.
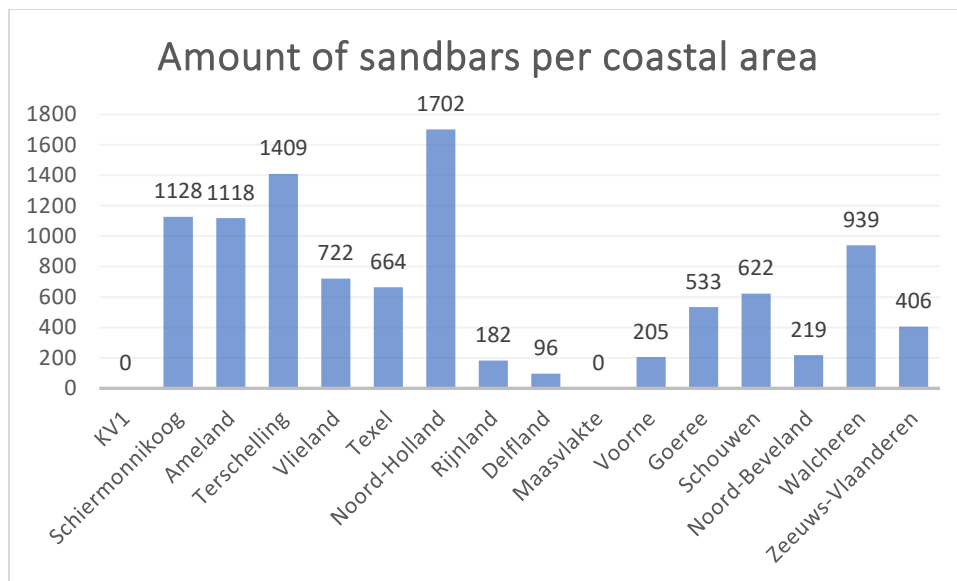

Figure 32: Detected sandbars at the Dutch coastal areas per coastal area (reference surface 2009)
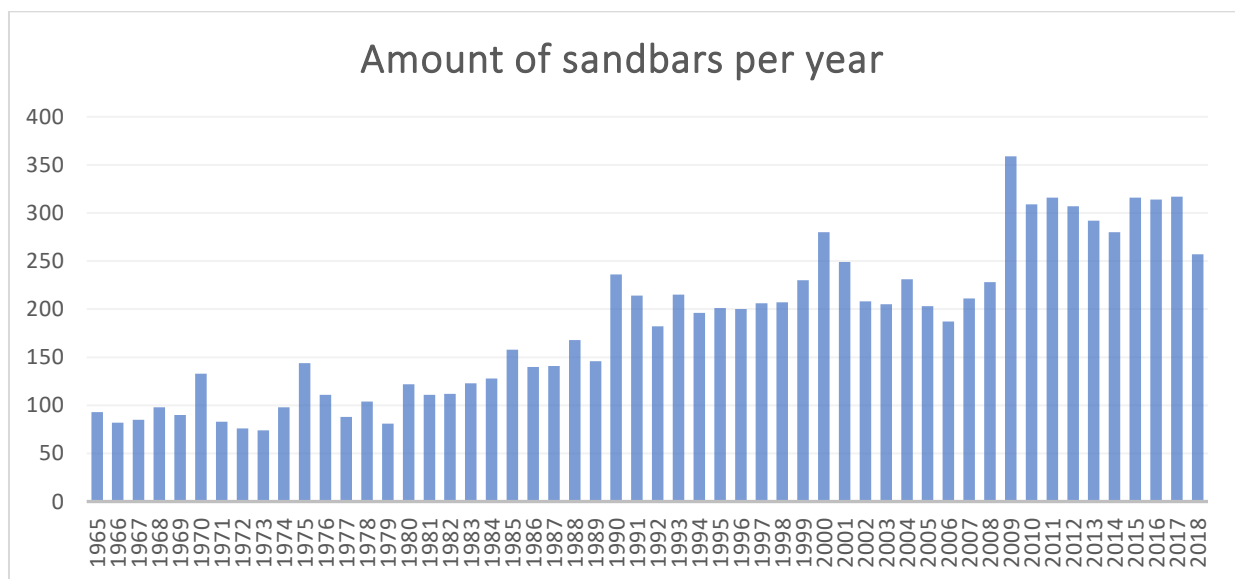

Figure 33: Detected sandbars at the Dutch coastal areas per year (reference surface 2009)

Besides the detection of sandbars per coastal area, it is interesting to look at the number of detected sandbars over the years. Figure 33 shows the detected sandbars per year when using the reference surface of 2009. It shows that in 1973 the least number of sandbars are detected in the data, there were only 74 sandbars detected. In general, the amount of detected sandbars is smaller in the earlier years when comparing it to recent years.

There are some years where the amount of detected sandbars slightly differs from the previous and next years. One of those examples is 1975. In 1975 there are more sandbars detected than the surrounding years. In the graphic in figure 29, it is shown as a peak related to the surrounding years. When the numbers are viewed, the difference between the number of detected sandbars in 1974, 1975 and 1976 is quite big. In 1974, 98 sandbars are detected while in 1975 there were 144 sandbars detected. This means that in 1975 almost 50% more sandbars were detected when comparing to 1974. On the other side, when comparing the numbers for 1975 and 1976, the amount of detected sandbars in 1976 is 20% less than in 1975. In 1976 the number of detected sandbars was 111. Besides this example, this pattern is also visible at the data of 1970, 1985 and 2000.

5.2.1 Shape

The shape of the detected sandbars is analysed with the PP test. The boxplots related to the PP test with the reference surface of 2009 can be found in Appendix D. The score on the PP test can be seen of each year. The closer the score to 1, the more circular the sandbar is while a score closer to 0 the shape of the sandbar is elongated.

In the data generated with the reference surface of 2009, it can be seen that there are outliers visible in more than one of the used datasets. The years with outliers in the data are 1970, 1979, 1986, 2000, 2001 and 2009. In the dataset of 2009, there were 5 outliers visible. Outliers are observations that are extremely high or low related to the other numbers within that dataset (McClave, Benson, Sincich, & Knypstra, 2014). In the data represented in this research, there are only outliers at the top of the boxplot which means that there are extremely high values. Extreme low values are not present in the data. There could be different reasons why there are extremely high values in the dataset. It could be that the value is wrong registered within the data or it could be that the outlier is a random outlier which has no reason (McClave et al., 2014). It is hard to say which reason applies in this case. Overall, the possible outliers must be removed from the dataset.

The minimum and maximum values are ranged around 0 and 1 in all datasets, which indicates that all datasets have an almost circular polygon (value closed at 1) and also a flattened out polygon (value closed to 0). The value 0 and 1 are not present in any dataset, this because there could be no perfect circle or a straight line. The median of all datasets lies between 0.25 and 0.45. There is one boxplot that differs from the rest when looking at the median.

5.3 Comparison with reference surface 1994

To compare the results of the reference surfaces used in this research, a t-test has been used. The purpose of this test is to see if there is a significant difference between the amount of generated sandbars of the different reference surfaces. Therefore the number of sandbars are divided into three different groups. The output is as follows:

Table 5: T-test of reference surfaces 1994 (Group1) and 1975 (Group2)

	Group	N	Mean
Sandbars	1	16	1322,75
	2	16	1613,25

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Sandbars	Equal variances assumed	,908	,348	-,588	30	,561	-290,500	494,354	-1300,106	719,106
	Equal variances not assumed			-,588	29,184	,561	-290,500	494,354	-1301,291	720,291

Table 5 shows the outcome of the t-test of the reference surfaces of 1994 en 1975. When looking at the Levene's Test for equality of Variances the F-value is 0.908 and the significance is 0.348. This means that in this situation the zero hypotheses should not be rejected. The probability of exceedance is 0.348 which is much bigger than the 0.05 tolerance. Therefore it could be said that both variances of the reference surfaces of 1994 and 1975 do not significantly deviate from each other. The significance of the equality of means is 0.561 and is higher than the standard criteria of 0.05. This means that there is no significant difference between the means of detected sandbars for both reference surfaces.

Table 6: T-test of reference surfaces 1994 (Group1) and 2009 (Group3)

	Group	N	Mean
Sandbars	1	16	1322,75
	3	16	621,56

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Sandbars	Equal variances assumed	7,429	,011	2,036	30	,051	701,188	344,342	-2,053	1404,428
	Equal variances not assumed			2,036	19,825	,055	701,188	344,342	-17,505	1419,880

Table 6 shows the results of the t-test of 1994 compared to 2009. The Levene's Test for the reference surfaces of 1994 and 2009 results in an F-value of 7.429 and a significance of 0.011. This means that in this situation the zero hypotheses should be rejected and the alternative hypothesis can be adopted. The probability of exceedance is 0.011 which is smaller than the 0.05 tolerance. Therefore it could be said that the variances of the reference surfaces of 1994 and 2009 do significantly deviate from each other. When looking at the t-test for equality of means there the significance is 0.051 which is higher than the criteria of 0.05. Therefore no conclusion can be made about the possible difference in the mean of the number of detected sandbars between the reference surfaces of 1994 and 2009.

Table 7: T-test of reference surfaces 1975 (Group2) and 2009 (Group3)

	Group	N	Mean
Sandbars	2	16	1613,25
	3	16	621,56

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Sandbars	Equal variances assumed	15,418	,000	2,484	30	,019	991,688	399,298	176,212	1807,163
	Equal variances not assumed			2,484	18,488	,023	991,688	399,298	154,377	1828,998

Besides the comparison of the original reference surface of 1994 with the alternative reference surfaces of 1975 and 2009, also a comparison between the alternative reference surfaces has been done. The results of this comparison can be seen in table 7.

In this analysis, there is an F-value of 15.418 and a significance of 0.000. This means that in this situation the zero hypotheses should be rejected and the alternative hypothesis can be adopted. The probability of exceedance is 0.000 which is much smaller than the 0.05 significance tolerance. This means that it could be said that the variances of the reference surfaces of 1975 and 2009 do significantly deviate from each other. When looking at the t-test for equality of means, the significance is 0.23 because it is assumed that the variances are not equal. This value is bigger than the criteria of 0.05. Thus, both means do not significantly differ from each other.

5.4 Smoothing polygons

Besides changing the reference surface, the smoothing of the polygons before calculating the PP-value which indicates the shape will be further analysed. As already said, besides the PAEK smoothing also the Bezier interpolation smoothing will be analysed. In table 8 the different statistics of both smoothing methods is shown. Both methods have the same N value. This because the comparison has been made over the same dataset with the same amount of polygons. The means of both smoothing techniques are quite similar: the Bezier technique results in a mean of 0.384 while the PAEK technique results in a mean of 0.38. The t-test of both techniques resulted in an F-value of 0.016 and a significance of 0.901. This means that the variances within both methods are similar. The null hypothesis should not be rejected. The probability of exceedance is 0.901 which is much bigger than the significance level of 0.05. When looking at the t-test for equality of means it is stated that both means do not significantly differ from each other because the significance is 0.228. This is bigger than the criteria of 0,05. This means that there is no significant evidence that both means differ from each other.

Table 8: Statistics of the Bezier and PAEK smoothing methods

Group Statistics

	Smooth_Method	N	Mean	Std. Deviation	Std. Error Mean
PP	Bez	9945	.3841323873	.2125579322	.0021314489
	PAEK	9945	.3804922340	.2130609882	.0021364933

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
PP	Equal variances assumed	,016	,901	1,206	19888	,228	.0036401533	.0030178930	-.002275168	.0095554749
	Equal variances not assumed			1,206	19887,889	,228	.0036401533	.0030178930	-.002275168	.0095554749

6. Conclusion

This research provided an insight into the pattern of sandbar migration near the Dutch coastal areas. Differ from earlier research, this research was based on the shape of the sandbars rather than the top of the sandbars. Based on the results some conclusions can be drawn. The key findings of the research questions are discussed below. In the end, some recommendations will be done for further research.

RQ1. What is the definition of sandbars and sandbar movement?
The definition of sandbars depends on which kind of sandbar is used in research. In this research, sandbars occurred in rivers were not included. The definition of sandbars in this research is based on the sandbars occurred in the near shoreline. Sandbars are not a phenomenon with one meaning, for example, there is more than one kind of sandbars that can appear near coastal areas. In this research the overall definition of the sandbar is as followed:

A sandbar is a sandy shoal that can occur near the coastline. A sandbar should follow a crescentic shape in one or more bars.

RQ2. How can sandbars be detected?
Sandbars can be detected using different data and different methods. Most researchers use ARGUS data for their sandbar analysis. It is a video remote sensing system. The methods used to analyse this kind of data are related to raster analysis.

In this research, the JARKUS dataset has been used to detect sandbars. Earlier research has shown that the method used for detecting sandbars were focused on the top of the sandbar within the line of each transact. In this research, the detection of sandbars went a step further. Not the top of the sandbar, but the shape of the sandbar is of importance. To accomplish this, several methods were used to finally detect the sandbars. The most important difference is the usage of a reference surface which at the end made the sandbars visual for the eye.

RQ3. How do sandbars change over time, is there a cycle or pattern visible?
The results clearly showed a movement of sandbars over time. The movement of sandbars are not bounded by a specific period in time but is visible over all the years from 1965 till 2018. These movements were not all the same and differ a lot from each other. Sandbars were detected which moved towards the coastal areas over a specific timeframe with an almost constant speed per year. Another movement which was clearly visible is the movement of the sandbar away from the coastal area. This movement is also been mentioned in earlier research and can be seen as the most common movement of sandbars. In this research, this movement appeared a lot but was not common. Other movements were made visible as well. There were some examples of sandbars that moved in random patterns, towards the coastal area and away. While other sandbars moved along the coastline. Therefore it could be concluded that there is no general movement of sandbars visible on the Dutch coastal area. Sandbars can move in different ways over time. This could be affected through for example wave impact or the direction of the wind.

The impact of external events like the implementation of beach replenishment cannot be seen in the results of this research. There is no sign of a faster migration of sandbars after the beach replenishment.

Besides movement, the shape of sandbars has also been analysed. In literature, it is stated that the size of sandbars decreases over time. In this research, this phenomenon was clearly visible when analysing the sandbars. Most sandbars are decreasing in size over time. Related to this decrease of size over time could be the PP-value which is used to analyse the shape of the sandbars. A general pattern has been discovered. This pattern shows a decrease in the PP-value when the area of the sandbar decreases. This means that when the area of the sandbar decrease, the sandbar become more elongated over time. The other way around, when the sandbar increase in size, the PP-value becomes higher, thus the sandbar has a rounder and compact form has also been proved.

Concluding, sandbars move over time and there are some patterns visible that returns and repeat over time, but a clear common movement is missing. When looking at the shape of sandbars, a pattern is covered related to the change of shape over time: How smaller the sandbar becomes, the more elongated. The bigger the sandbar becomes, the more compact and round its shape is.

RQ4. To what extent does a change of parameters affect the results?

Different changes in the data were made to see if changing factors will affect the outcome. Besides the original reference surface of 1994, two other reference surfaces have been made of data from 1975 and 2009. The results were compared with the original data. All reference surface had an almost constant slope with a slope of most pixels between $0 - 5\%$. This means all three reference surfaces were made sufficient to use for data analysis.

The first comparison has been made between the number of sandbars detected. There were differences visible when looking at the absolute numbers of the detected sandbars. But overall, it is stated that in the bigger coastal areas, more sandbars were detected. Besides this, also in the North of the Netherlands, at the islands of the Netherlands, more sandbars were detected than in the South of the Netherlands. This is seen at the outputs of all three reference surfaces. Over time, there were more differences between the three reference surfaces. There is no clear visible similarity between the three reference surfaces. In the data, it became visible that the usage of the data of the reference surface can have an impact on the results when looking at the number of detected sandbars. It is shown that in the data of the year which is used as a reference surface, more sandbars are detected than in the surrounding years.

Besides the number of sandbars also the means of the detected sandbars were compared. The reference surface of 1994 and 1975 do not have a significant difference between the mean of the number of detected sandbars. This is also the case when comparing the means of the reference surfaces of 1994 and 2009 and the comparison between the reference surfaces of 1975 and 2009.

Another factor that can change the results would be the smoothing of the polygons before calculating the PP-test which indicates the form of the sandbars. The see if there was a significant impact, the Bezier interpolation smoothing was used to calculate the PP-value besides the PAEK test. The test showed that there is no significant evidence that both means differ from each other. This means that the usage of the Bezier test or the PAEK test should not have a significant impact on the mean of the PP-values.

The results of this research are not easy to compare to other research. This because other research is mainly focused on the top of the sandbars rather than the shape of the sandbars.

The answers to these research question are used to provide an answer to the main research question:

What deviations within the cycle of sandbar movement can be detected, on the Dutch coastal areas, over time (1965 – 2018)?

The answer to this main question is that no deviations can be detected within the cycle or pattern of sandbar movement. This because there is no clear pattern visible where deviation should be detected. Specific sandbars have specific movements over time.

7. Discussion and recommendation

As already said at the beginning of this thesis, the discussion of the results is included in the results chapter. However, this chapter gives a summary of the discussion of the results related to earlier research. Besides the discussion, this chapter gives some limitations of this research and some recommendations for further research.

First of all when looking at the results of the reference surface used it can be said that most research done, only looked at the definition of sandbars by their highest point instead of their shape. For example Ruessink and Terwindt (2000). In their research, they look at the cross-shore profile of a sandbar per transact where the highest point of the sandbar the reference is for movement. There are research done not looking only at the top of the sandbar but more general looking at the whole bathymetry of where the sandbar is recognised. Those researches (Bailey & Shand, 2002; G. Ruessink et al., 2013; van Enckevort et al., 2004; Walstra, Wesselman, van der Deijl, & Ruessink, 2016) are based on photogrammetric or lidar data, which is different of the JARKUS data used in this research. Thus, both kinds of research do not have a general definition of a sandbar because both types of research are different. The research done in this thesis differs from the two above stated research types because it uses a reference surface to explore the shape of the sandbar. Therefore, there is no definition given in this specific context. The definition used in this thesis is based on a definition of an earlier thesis related to this specific topic namely from Arno Timmer (2017). The definition is further gathered through knowledge about the topic generated throughout the process.

The shapes of sandbars found in this research can be discussed with the literature about sandbar shapes. In this research crescentic formed sandbars are formed. In earlier research crescentic formed sandbars were found along the Dutch coastal area (Ruessink & Kroon, 1994; van Enckevort et al., 2004). Van Enckevort research was focused on the coastal area of Noordwijk while Ruessink researched the coastal area of Terschelling. At both locations, crescentic formed bars were found. In this research different crescentic formed bars were found like the one at the coastal area of Noord Holland in 2005 as seen in figure 20. Besides the form of the sandbar, most sandbars in this research are situated parallel at the coastal area which is a common given when looking at earlier research (King & Williams, 1949; Ruessink & Kroon, 1994; van Enckevort et al., 2004).

Literature about the forming of sandbars also mentioned the appearance of a double sandbar system (Ruessink et al., 2013). In this research some of those double sandbar systems where detected and got some similarities with literature. An example can be seen in figure 23 where the movement of several sandbars at the coastal area at Terschelling from 1986 till 1989 is visualised. The double sandbar system is there visible including its movement. Ruessink, Price and Castello (2013) mentioned that mostly the inner sandbar is smaller than the outer sandbar. In this case, both sandbars are quite the same size and thus does not match the literature. It can also be seen that some of the bars in this figure contradict the allegation of Ruessink (2013). The outer bars are smaller than the inner bars.

Looking at the movement of sandbars research stated that sandbars are moving away from the coastal areas over time (Van Enckevort & Ruessink, 2003). Other research suggests a more dynamic movement of sandbars towards and away from the coastal area (Ruessink, Lodder, Ramaekers, Vonhögen-Peeters, & van der Grinten, 2012). In this research, there is no clear movement pattern related to research. There are sandbars detected which do move only towards the coastal area. However, there are also sandbars detected which firstly move towards and then away from the coastal area. Nevertheless, there is also a movement detected which are not described in the literature. An example of this movement can be seen in figure 25. This example

shows a movement along the Dutch coastal area instead of towards or away from. This is an interesting movement which could be taken into account in further research.

Besides the discussion about the results, a discussion about the limitation of this research can be held because every research has its limits that must be addressed.

In this research, some methodological decisions could have affected the results. First, the interpolation techniques. The decision of the TIN interpolation is based on literature that said that generate the TIN interpolation will result in a surface with an (almost) straight slope. In this research, this is accomplished but it has to be marked that the focus of this thesis was not to find the best interpolation technique.

Another point is the decision to use a reference surface for the detection of sandbars. In literature, no reference has been found that substantiate the usage of a reference surface for sandbar detection. Nevertheless, because of time constraints, only three reference surfaces has been made. The results showed that using a specific reference surface could have an impact on the results. This could be something that can be further investigated. Further research can be done to find the optimal usage of a reference surface in sandbar detection.

A recommendation related to sandbar detection would be to see if there is a difference in detection of the shape of sandbars when looking at the ARGUS data and the JARKUS data. This because both datasets are different from each other and it could be interesting to see if the results differ.

Further research could also dig further in the movement of sandbars related to direction, as already said earlier. In this research, it is shown that sandbars do not only move towards and away from the coastal area, but also along the coast. It can be interesting to see if these movements are local or that they appear at different coastal areas on the Dutch coast or even at other coasts over the world.

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Appendix A – Python script concatenate .csv files

```python
1  import os
2  import glob
3  import pandas
4
5  def concatenate(indir= #location input folder
6  ,outfile= #location output
7  ):
8      os.chdir(indir)
9      fileList=glob.glob("*.csv")
10     dfList=[]
11     for filename in fileList:
12         print(filename)
13         df=pandas.read_csv(filename,header=None)
14         dfList.append(df)
15     concatDf=pandas.concat(dfList,axis=0)
16     concatDf.to_csv(outfile,index=None)
```

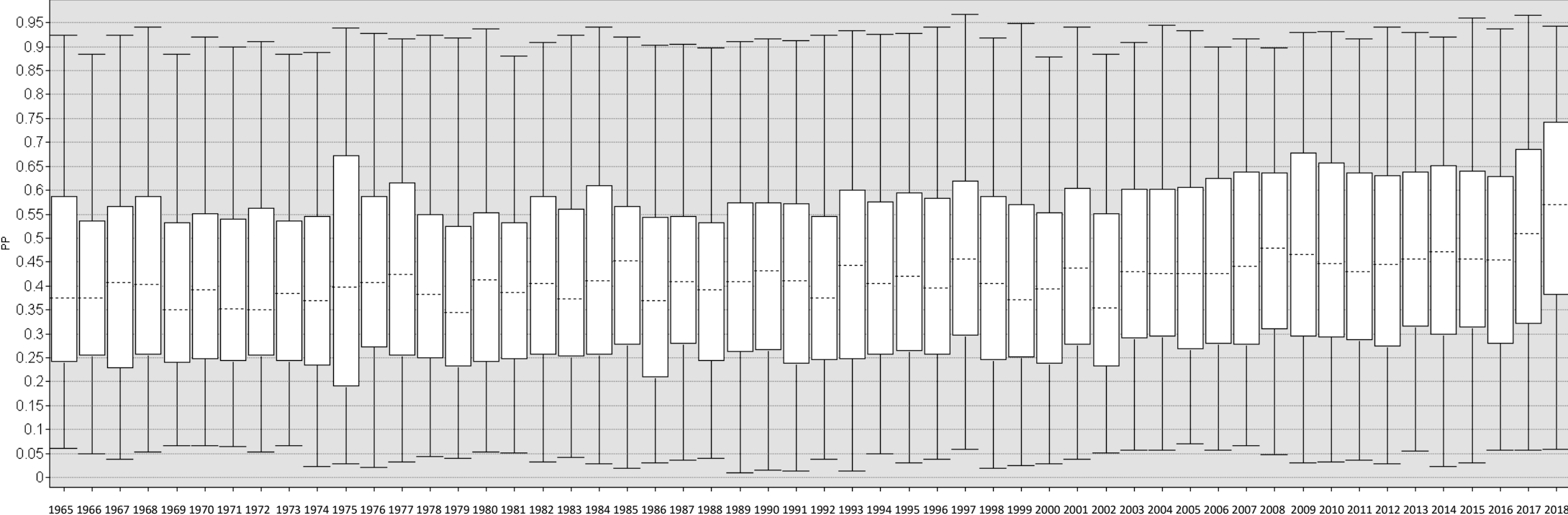## Appendix B – Boxplots Polsby-Popper test with 1994 reference surface

Boxplots Polsby-Popper test 1965-2018
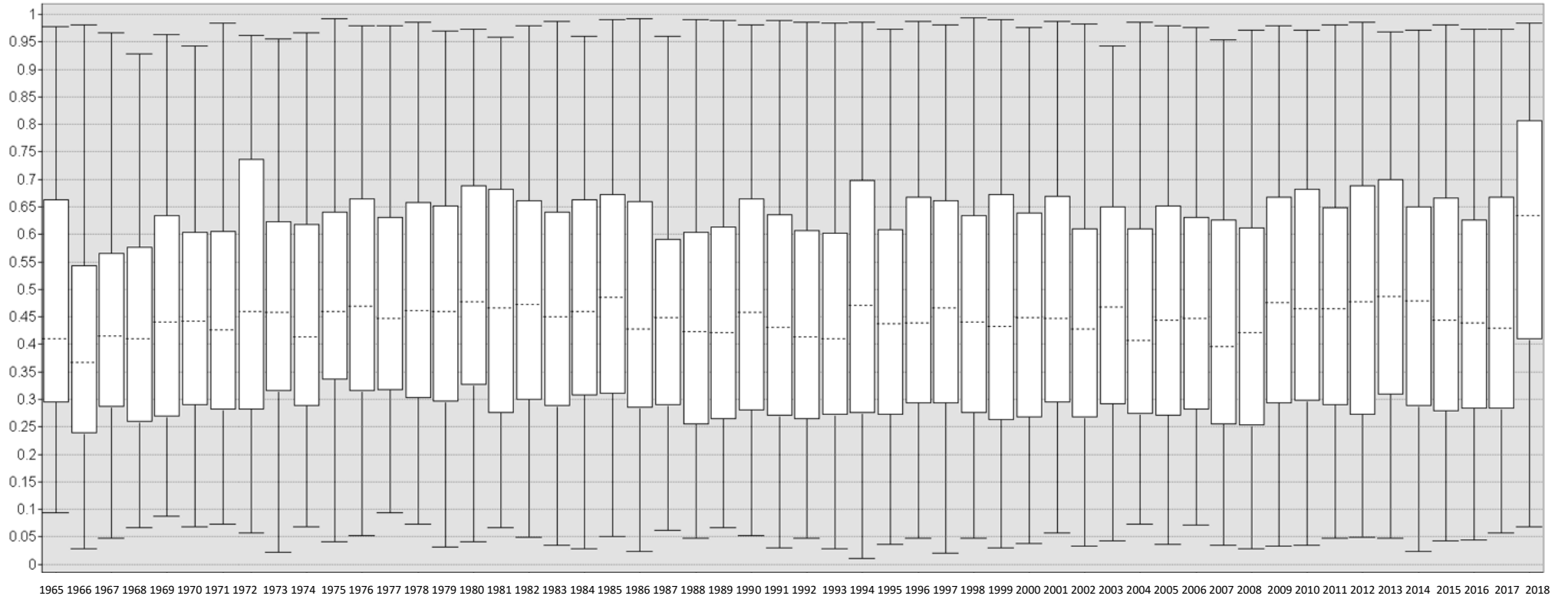
Appendix C - Boxplots Polsby-Popper test with 1975 reference surface

Boxplots Polsby-Popper test 1965-2018

Appendix D – Boxplots Polsby-Popper test with 2009 reference surface

Boxplots Polsby-Popper test 1965-2018