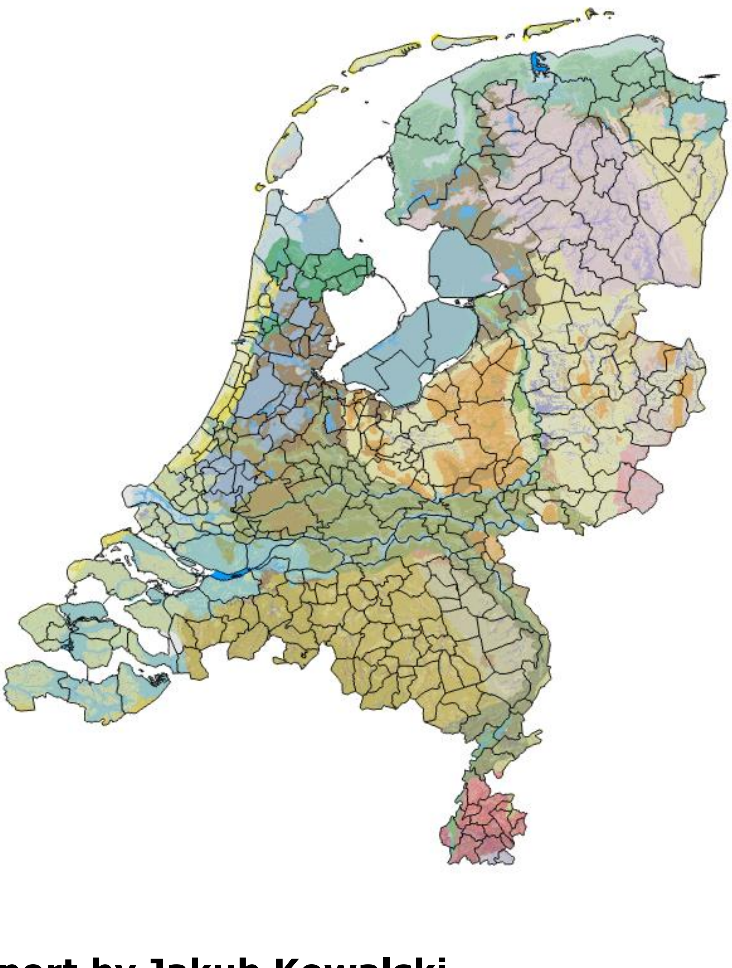
GRS50806
Geo-information Science BSc research project

Exploring the 200-year relationship between Dutch municipal boundaries and the natural substratum using open data



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BSc Minor Geo-information for Environment & Society

Exploring the 200-year relationship between Dutch municipal boundaries and the natural substratum using open data

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Table of contents

1. Introduction

1.1 Background

The Dutch municipalities are the third tier of governmental administration in the Netherlands and in practical terms, they are the subdivisions of the twelve provinces. Their boundaries were regularly redrawn and merged as the all-time high of 1249 municipalities in 1820 was reduced to the all-time low of 355 in the year 2020 (Table 1). Similarly, the factors which determine the exact placement of the municipal borders have developed just as much in during this time period.

Before and in the beginning of the 19th century, the boundaries of Dutch municipalities were determined based on local preferences which either selected for arbitrary distinctions or actual differences in the natural substratum of the landscape in addition to cadastral maps (Boonstra & van der Meer, 2011). The term "natural substratum" specifically refers to various natural phenomena which can be bundled under two fields of geomorphology and hydrology. Geomorphology contains the various traits and characteristics which determine the development and current form of the landscape (Stetler, 2014). On the other hand, hydrology includes the distribution and movement of water below and under the surface (Marshall, 2013). Both fields describe the various characteristics of the landscape which initially influenced the placement of municipal borders, but eventually fell out of favor for other factors in the Netherlands (Boonstra & van der Meer, 2011).

As time progressed, socio-economic factors became the drives of changes to borders with many mergers of municipalities and the redrawing of their boundaries as a consequence. Two key points in the history of Dutch administrations can be highlighted due to their extreme influence on the development of municipal boundaries. The first Gemeentewet of 1851 resulted in a drastic reduction in the amount of municipalities although many of the changes only became visible in the following decade (Beekink & Ekamper, 1999). The second Gemeentewet of 1992 only accelerated the reduction in the number of municipalities as by 1994 they amounted to barely half of the previous century.

As socio-economic factors became the primary drivers of changes to municipal boundaries, their extent of relationship with the geomorphology and hydrology was not studied. Preceding this study, no literature was identified which handled the topic of the relationship between municipal boundaries and the natural substratum in the Netherlands. As the number of municipalities has continued to diminish in the past two centuries, it is increasingly important to understand how this relationship has developed. By exploring this relationship, future changes to municipal boundaries may be determined by more than just socio-economic

Table 1. Change in the number of municipalities from 1820 to 2020

Province	Year												
	1820	1840	1860	1880	1900	1920	1940	1960	1980	1994	2000	2010	2020
Groningen	62	57	57	57	57	57	57	56	50	25	25	26	12
Friesland	43	43	43	43	43	43	42	44	44	31	31	31	18
Drenthe	33	33	33	33	34	34	34	34	34	34	13	12	12
Overijssel	62	62	61	61	61	60	54	53	47	45	44	25	25
Flevoland*	0	0	0	0	0	0	0	0	0	6	6	6	6
Gelderland	120	118	116	116	116	115	112	105	95	86	78	56	51
Utrecht	97	92	72	72	72	72	71	58	48	39	37	29	26
Noord-Holland	149	147	136	134	134	134	125	119	81	70	70	60	47
Zuid-Holland	251	241	197	192	188	186	179	169	144	95	94	77	52
Zeeland	117	116	113	111	109	109	106	101	30	30	17	13	13
Noord-Brabant	189	185	185	184	184	179	152	141	131	120	70	68	62
Limburg	126	125	125	124	123	121	121	110	104	57	54	41	31
Total	**1249**	**1219**	**1138**	**1127**	**1121**	**1110**	**1053**	**990**	**808**	**638**	**539**	**444**	**355**
Diff. previous	*0*	*-30*	*-81*	*-11*	*-6*	*-11*	*-57*	*-63*	*-182*	*-170*	*-99*	*-95*	*-89*

factors such as the eco-system services of each landscape type. As the environment takes a more leading role in national policy, the natural substratum of the country should be studied in greater detail to determine the future development of administrative boundaries.

By matching the geomorphology with the current and historic municipal boundaries in the European Netherlands, this study will explore the relationship between the Dutch municipalities and the natural substratum of the landscape. As a result, this project will contribute towards future adjustment and merging of municipal borders

1.2 Structure of the report

The report is structured as follows: Chapter 2 introduces the research objective, questions and delineation. Chapter 3 presents the research methodology by first listing the sources and method of data acquisition. Second, it describes the process of data assessment and lists the selected source data. Third, it shows the method of data processing in the form of workflow models and short descriptions for each section of the models. Chapter 4 answers and presents the results for each of the three secondary research questions. Chapter 5 discusses the results, further application of the study and the limitations of the research. Chapter 6 concludes the study and answers the general research question. Annex A contains a map of the geomorphology overlayed with the municipal boundaries of 2020.

2. Research approach

2.1 Research objective

The objective of the study is to explore the relationship between the Dutch municipalities and the natural substratum by matching the geomorphology with the current and historic municipal boundaries in the European Netherlands.

2.2 Research questions

Following the objective of the study, the general research question is:

What is the relationship between the natural substratum and the municipal boundaries in the European Netherlands?

The general research question is further subdivided into questions which specifically correspond to each of the three deliverables that are expected for this study. The full list of secondary research questions (SRQ) is as follows:

1. How have the Dutch municipal boundaries changed between 1820 and 2020?
2. What is the overlap between the geomorphology and the current Dutch municipal boundaries in the year 2020?
3. What is the overlap between the geomorphology and the historic municipal boundaries in the European Netherlands in the years 1820, 1860, 1920 and 1994?

2.3 Research delineation

To delineate the study, this chapter will first set the boundaries of the research area. Second, the temporal extent and time intervals of the research will be introduced. Finally, the extent of the analysis of the relationship between the municipal boundaries and the natural substratum will be explained in detail.

As indicated in the research objective and questions, the research area of this study includes the entire European Netherlands. It thus excludes the Dutch overseas territories in the Caribbean, but it still includes the islands in Europe. The Caribbean territories were excluded as they are not part of the twelve Dutch provinces and their boundaries have not changed in the study's temporal extent. The European islands were included as they are each part of a province, and many contain the borders of multiple municipalities as is the case in Zeeland. By including them, the boundaries of all Dutch municipalities are included in the research.

The temporal extent of the study was chosen with the years 1820 and 2020 as the start and end dates respectively. This starting year was selected because it included the highest number of municipalities that had ever existed simultaneously in the Netherlands. The ending year of 2020 was selected due to the availability of the most recent geomorphology dataset from 2019. The year 2020 was ultimately selected in favor of 2019 to create a more uniform temporal extent of the study. The time intervals of 1860, 1920 and 1994 were selected based primarily on two important events which heavily influenced the development of municipal boundaries in the Netherlands. Year 1860 may be seen as the culmination of the changes resulting from the first Gemeentewet which was implemented in 1851. Similarly, year 1994 was chosen because it captures most of the boundary changes which resulted from the second Gemeentewet in 1991. The year 1920 was chosen as a mid-point to balance the time intervals.

The analysis of the relationship between the natural substratum, and the current and historic municipal boundaries will be limited only to the overlap with the geomorphology. This will include the surface water bodies, but the relationship of watersheds and drainage basins will not be included in this research despite their influence on the development of geopolitical boundaries. The reasons for excluding the analysis of hydrological overlap from this study will be explained in chapter 4.

3. Methodology

3.1 Data acquisition

The acquired data is divided into two types: literature and geodata. The study of literature was the primary source of information regarding the history of Dutch municipalities, and it was used select the temporal extent and time intervals of the study. To obtain this literature, the following online sources were used: WUR Library, Scotus and Google Scholar. Additional articles were obtained through the snowball method or they were directly recommended by the research supervisor. To identify the relevant online sources of information regarding the development of municipal boundaries in the Netherlands, the following Boolean combinations were utilized as search terms: (1) “gemeente AND geschiedenis”, (2) “gemeente AND herinrichting”, (3) “grenzen AND landschap”, (4) “morfologie AND grenzen”.

The second type, geodata, was obtained for the analysis of changes to municipal borders and their overlap with the geomorphology. It was acquired using online sources such as the ArcGIS Living Atlas portal and the DANS archive. The following Boolean search terms were used to identify the datasets: (1) “gemeente AND grenzen AND geschiedenis”, (2) “landschap AND data AND Nederland”, (3) “morfologie AND data AND Nederland”, (4) “CBS AND gemeente”.

3.2 Data assessment

A visual data assessment was carried out during the acquisition of geodata to determine its suitability for the purposes of the study. The final list of the source geodata is presented in table 2. The datasets of the historic boundaries were selected based on availability. The shapefiles made available by Boonstra (2007) were the only available dataset that covered the project’s temporal extent, and they were thus selected as one of the sources. *CBS’ Wijk- en buurtkaart 2020* was selected as the source data for the current boundaries as it was immediately available from a reputable source for download from the Living Atlas. The geomorphological data was assessed based on its level of detail and quantity of classes. The *Archeologische Landschappenkaart* was chosen because it included a sufficiently large number of classes while still preserving a clear division of areas.

Table 3. Final list of source data

Name of dataset(s)	Description	Reference
‘’nl_1820_gemeenten’’, ‘’nl_1860_gemeenten’’, ‘’nl_1920_gemeenten’’, ‘’nl_1994_gemeenten’’	Dutch municipal boundaries in the years 1820, 1860, 1920 and 1994.	Boonstra (2007)
“CBS_WijkEnBuurtkaart2020”	*Dutch municipal boundaries and neighborhoods in 2020 with additional demographic data*	Centraal Bureau voor de Statistiek (2021)
“Archeologische LandschappenkaartNL”	*Geomorphology of the European Netherlands with 26 individual types of landscapes.*	Rensink (2020)

3.3 Data processing in ArcGIS Pro

The source data was processed according to the general methodology (Figure 1). Sub-methodology A corresponds to SRQ1, and B covers SRQs 2 and 3. The processing of data was performed both in ArcGIS Pro and Excel and only the ArcGIS methodology is included in the workflow model. The project results are listed in the table below:

Table 5. List of project results

Name	Type	Sub-methodology	Included in report
BMa0PreprocessingBoundaryChange	Python file	A	
BMa1TransformationToPolyline	Python file	A	
BMa2CalculateAreaChange	Python file	B	
pra0Timelapse	GIF	A	
pra2BoundaryChange	Excel: table and graph	A	Table 4
pra2NumberChange	Excel: table and graph	A	Table 1 (p.1)
prb1BoundaryOverlap	Excel: table and graph	B	Table 5; Figures 2, 3 and 4; Annex A

3.3.1 Sub-methodology A: boundary change

Section A corresponds to SRQ1 and it covers the ArcGIS models: BMa0PreprocessingDatasetBoundaries, BMa1TransformationToPolyline and BMa2CalcualteAreaChange. First, the source data of municipal boundaries were copied, and the projection was defined to RD New. Second, the fields "Time_start" and "Time_end" were added to each of the five datasets and their value was set to the corresponding year. Third, the datasets were merged into a single file after which the start and end time fields were defined in the properties of the feature class in order to create a timelapse. The first project deliverable, pra0Timelapse, was created by selecting keyframes of each year and exporting the animation as a GIF file. The second deliverable was created by exporting the individual boundary datasets to Excel where they were processed further. Fourth, the boundary polygons were transformed into lines and a buffer of 3 meters was created around them for the calculations of overlap in sub-methodology B. The choice of the buffer size will be further discussed in Chapter 4. The option "No Dissolve" is chosen to preserve the names of each municipality for the resultant buffers.

In Excel, the exported data was processed with the goal of obtaining four kinds of information about each municipality for each year: total area in km2, perimeter in km, and the ratios between the 2020 and 1820 values for the two variables. Additionally, the average municipal area and perimeter were calculated for each year. As indicated in Table 3, these results are delivered separately from the report. Additionally, the number of municipalities was also calculated in roughly 20-year intervals between 1820 and 2020 (Table 1). The table contains information about the exact number of municipalities for each date and the difference compared to the previous year.

3.3.2 Sub-methodology B: geomorphology overlap

Section B covers SRQs 2 and 3, and it includes the ArcGIS model BMb1OverlapGeomorphology. First, the buffer features from sub-methodology A were intersected with the geomorphology source data. Second, the tool Summary Statistics was used to obtain the Shape_Area for the case field LscpZoneNa. Third, the five resulting tables were exported to Excel for further processing.

In Excel, the exported data was used to calculate percentages of the total boundary area occupied by each geomorphological class for each of the five years. The classes which make up the top 60% for any of the years will be selected and visualized in the following products: (1) overview table for the five years, (2) pie chart for 2020 (3) and a pie chart of the five years.

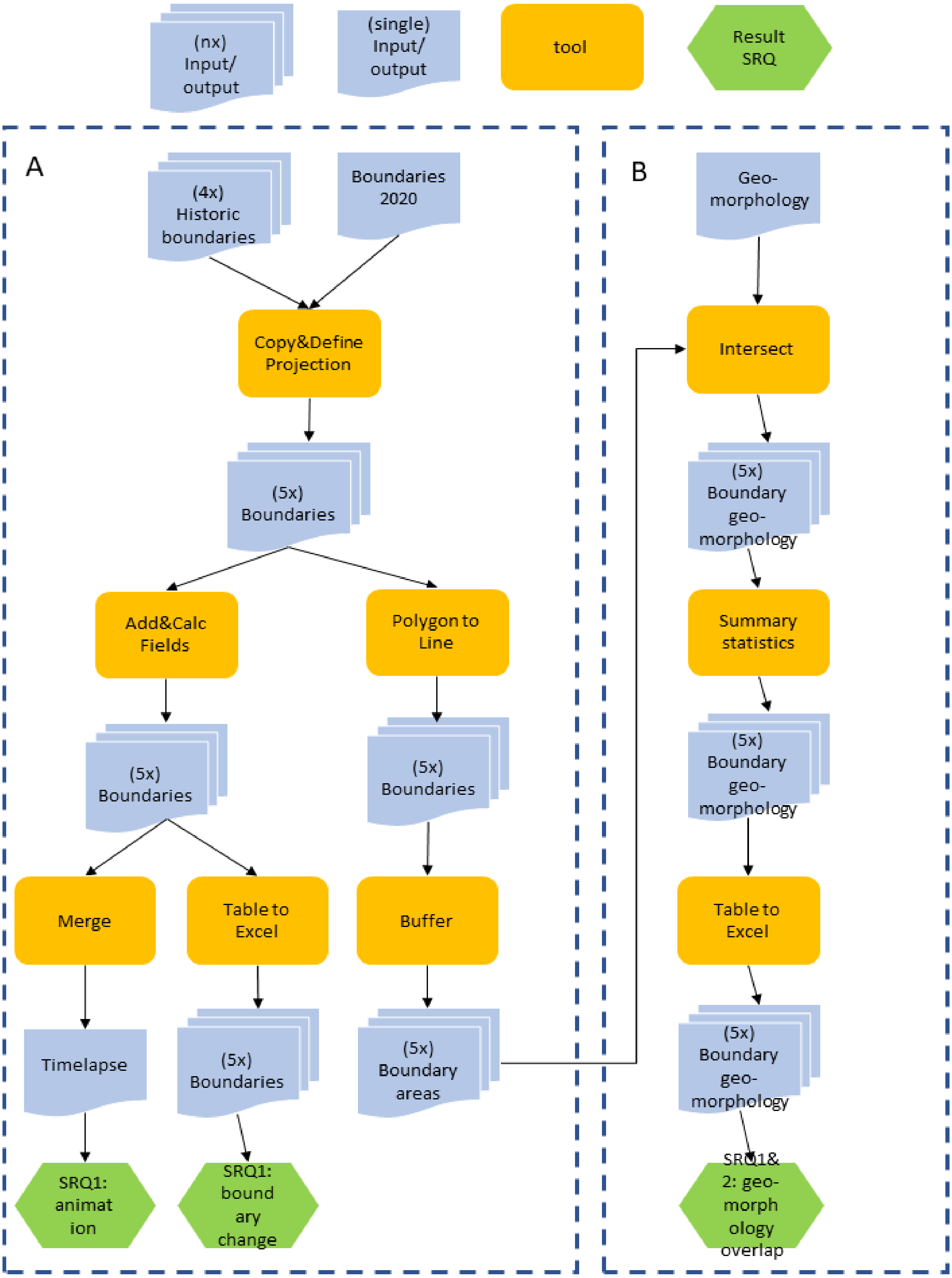

Figure 1. Workflow model of the data processing methodology in ArcGIS Pro

4. Results

4.1 Changes to municipal boundaries

The number, average area and average perimeter of the Dutch municipalities has changed significantly throughout the last 200 years. As displayed in Table 4, there is a clear pattern where the number of municipalities in the Netherlands has decreased over the years while their average area and perimeter has increased. To illustrate these changes to municipal boundaries, the areas of Sluis and Urk will be explained in detail.

Sluis was selected as an example because it best exemplifies the changes to municipal areas due to the mergers of local governments. This municipality experienced the highest increase in total area from 1.53 km^2 in 1820 to 283.24 km^2 in 2020 (Table 4). The area of Zeeuws-Vlaanderen counted 38 individual municipalities at the start of the study's chosen timeframe. But in 2020, the region contained only three municipalities in total. Sluis' growth is a result of many municipal mergers, and it serves as an example of just how drastically the average area of Dutch municipalities was affected by this factor.

On the other hand, Urk exemplifies changes to municipal boundaries as a result of the Dutch policy of land reclamation in the latter half of the 20th century. Initially an island, Urk is now connected by land to the rest of the Netherland through the Noordoostpolder whose process of reclamation started in 1937 (van der Wal & van Oosterhout, 2017). The creation of the Noordoostpolder and the neighboring Flevopolder also resulted in the creation of six municipalities as part of the new province of Flevoland in 1986 and a significant increase of Urk's area.

Table 7. The change of the number, perimeter (PM) and area of Dutch municipalities

Year	Nr. mun.	Avg. PM (km)	Av. area (km^2)	PM (km)	Area (km^2)	PM (km)	Area (km^2)
1820	1248	22.93	25.77	5.32	1.53	4.46	0.96
1860	1138	24.58	28.53	5.32	1.53	4.46	0.96
1920	1110	25.07	29.38	24.27	23.30	4.46	0.96
1994	638	35.73	54.18	38.10	34.35	11.11	6.33
2020	355	57.17	95.04	125.21	283.24	20.88	13.42
Increase (%)	**-72**	**149**	**269**	**2253**	**18453**	**369**	**1299**

4.2 Geomorphology overlap

Analysis of the overlap of geomorphology with the municipal boundaries found seven landscape types which consistently returned more than 60% of the total boundary area for each year (Table 5, Figure 2). The Dutch municipal boundaries in 2020 overlap for more than 50% with the following four geomorphological classes in a descending order of area percentages: salt marshes, sand cover plains, open water and peatland.

Table 9. The change of the overlap of geomorphological classes and Dutch municipal boundaries

Zones	Area1820 (%)	Area1860 (%)	Area1920 (%)	Area1994 (%)	Area2020 (%)
Sand cover plains *Dekzandvlakten*	14.95	15.12	15.05	16.72	15.93
Salt marshes *Kwelders*	19.54	19.45	19.42	16.36	18.22
Surface waterbodies *Open water*	5.40	5.52	5.75	6.93	14.00
Floodplain *Overstromingsvlakte*	7.39	7.21	7.26	6.46	4.04
Peatland *Veenvlakten*	9.33	9.12	8.98	8.13	6.14
Stream valley *Beekdalbodems*	3.94	4.00	3.96	4.38	5.76
River floodplain *Uiterwaarden*	4.02	4.09	4.15	4.82	0.65
Remaining 35 classes	35.44	35.49	39.59	36.19	35.26

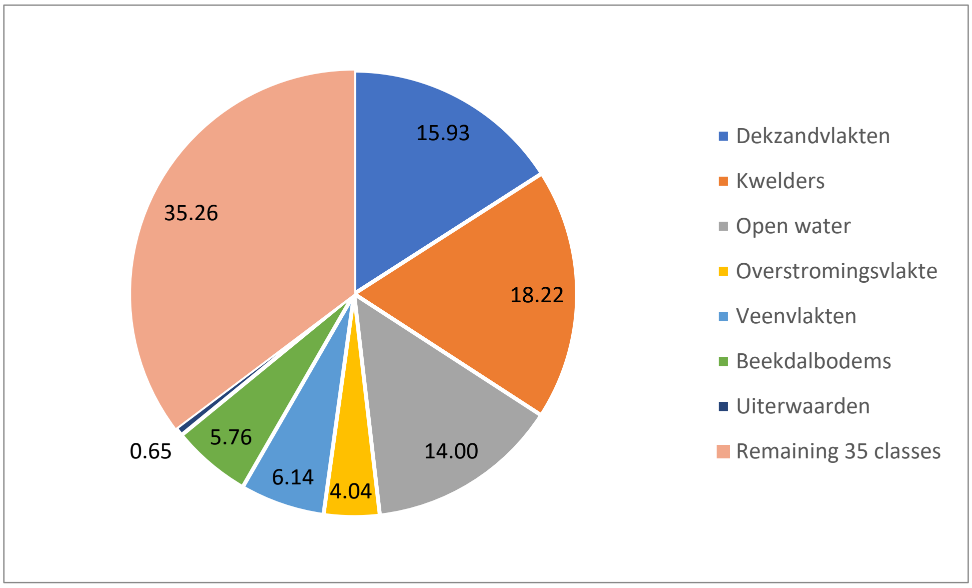

Figure 2. Percentage of total boundary area in 2020 that overlaps with geomorphological areas

4.3 Historic geomorphology overlap

As visible in Table 5, the top seven classes consistently score between 60 and 65% of the total boundary area although the exact area percentages for each class differ significantly between the starting and ending years. The percentages show relatively little changes between the years 1820, 1860 and 1920; but from 1994 to 2020, there is significant development in the overlap of the municipal boundaries with the class “open water” (Figure 3). Similarly, there is a relatively sharp drop in the area percentage of the salt marches class when comparing the year 1994 with 1920. For comparison with the results of 2020, the four geomorphological classes with the highest percentages in 1820 are the following: salt marshes, sand cover plains, peatland and floodplains (Figure 4). Floodplains occupy a significant portion of area unlike in 2020 where open water holds a far greater percentage. Throughout these changes, the class of salt marshes has the highest area percentages for all years expect for 1994 where the boundaries overlap slightly more with the sand cover plains.

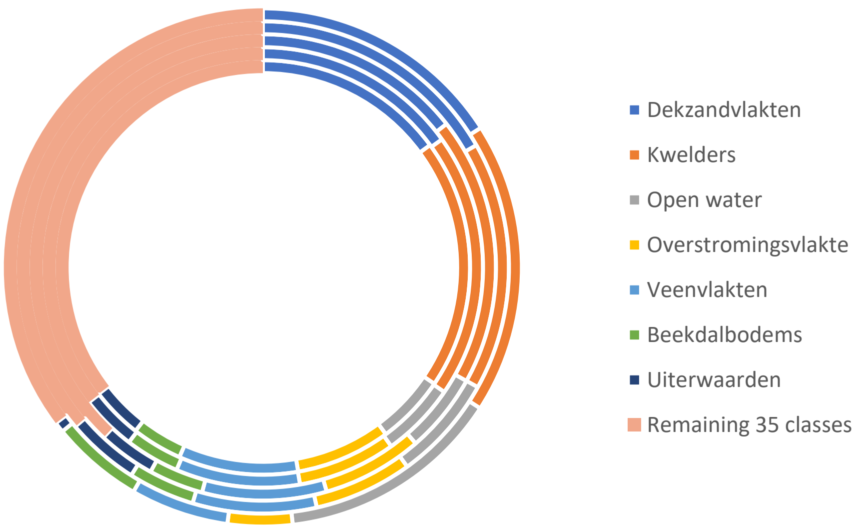

Figure 3. Percentage of total boundary area from 1820 (innermost circle) to 2020 (outermost) that overlaps with geomorphological areas

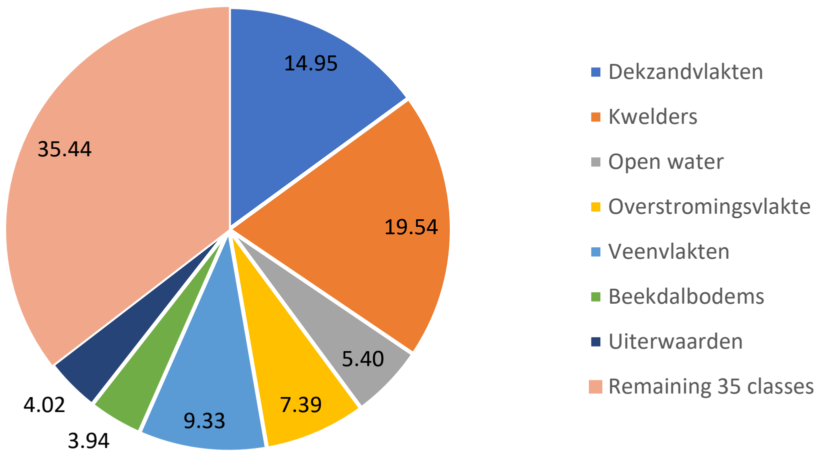

Figure 4. Percentage of total boundary area in 1820 that overlaps with geomorphological areas

5. Discussion

In this chapter, the validity of the methodology and the applicability of the results to each of the research questions will be analyzed in detail. For the methodology, several decisions were taken because of the project's short timeframe with possible inaccuracies in the results of the study as a consequence. The chosen size of the buffers was 3 meters. Comparison was made with the overlap results for sizes of 6 and 9 meters and no significant difference was identified. Comparison could not be performed for sizes greater or equal to 12 meters due consistent errors during the execution of the ArcGIS model. Time constraints did not allow for in-depth analysis for the cause of the errors. The quality of the methodology is also limited by the quality of the source datasets. The historic boundaries are vastly simplified compared to the boundaries of 2020 and no suitable substitute were identified during the research

Furthermore, the results of the research may fail to fully represent the relationship between the Dutch municipal boundaries and the natural substratum. The latter two secondary research questions have only analyzed the relationship between the geomorphological classes and the boundaries. Despite the inclusion of surface water bodies in the geomorphology dataset, the project fails to properly research the relationship between boundaries with other hydrological characteristics of the landscape. Analysis of hydrology could not be performed due to the time constraints of the study and the large scale of the research area. Comparison of only the current geomorphological situation with the historic boundaries fails to fully represent the past relationship between these two elements.

Despite these faults, it is important to highlight the novelty of the research. As mentioned in the introduction, no comparable literature or research was identified prior to this study. By overlapping the current and historic boundaries with the map of geomorphological classes, even if faulty, is the first step in the application of GIS to the analysis of the relationship between the political boundaries and the landscape. Additionally, the study is the first to analyze the exact development in the average area of Dutch municipalities over such a large temporal extent.

6. Conclusion

The main objective of the research was to explore the relationship municipal boundaries and the natural substratum in the European Netherlands by calculating overlap between the geomorphology and the municipal boundaries between 1820 and 2020. The study found recurrent overlap which accounted for at least 60% of the total boundary area with the following geomorphological classes: sand cover plains, salt marshes, surface water bodies, floodplains, peatland, stream valleys and river floodplains.

However, the results of the study failed to account for the hydrological characteristics of the landscape and further research is necessary to explore the relationship between the natural substratum and the boundaries on a more detailed level. Additionally, the methodology of the study may be improved by repeated calculation of the overlap with a wider range of buffer sizes. Future research may avoid these issues by limiting its study area to the provincial level within the Netherlands which will allow for in-depth analysis of the hydrology and possible correction of the errors between the datasets of the municipal boundaries. By continuing the research of the relationship between the political boundaries and the natural substratum, future municipal mergers and redrawing of borders may be better informed and result in changes that are more reflective of the environment.

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Annex A

Figure 5. Overlap of municipal boundaries from 2020 with the map of geomorphology