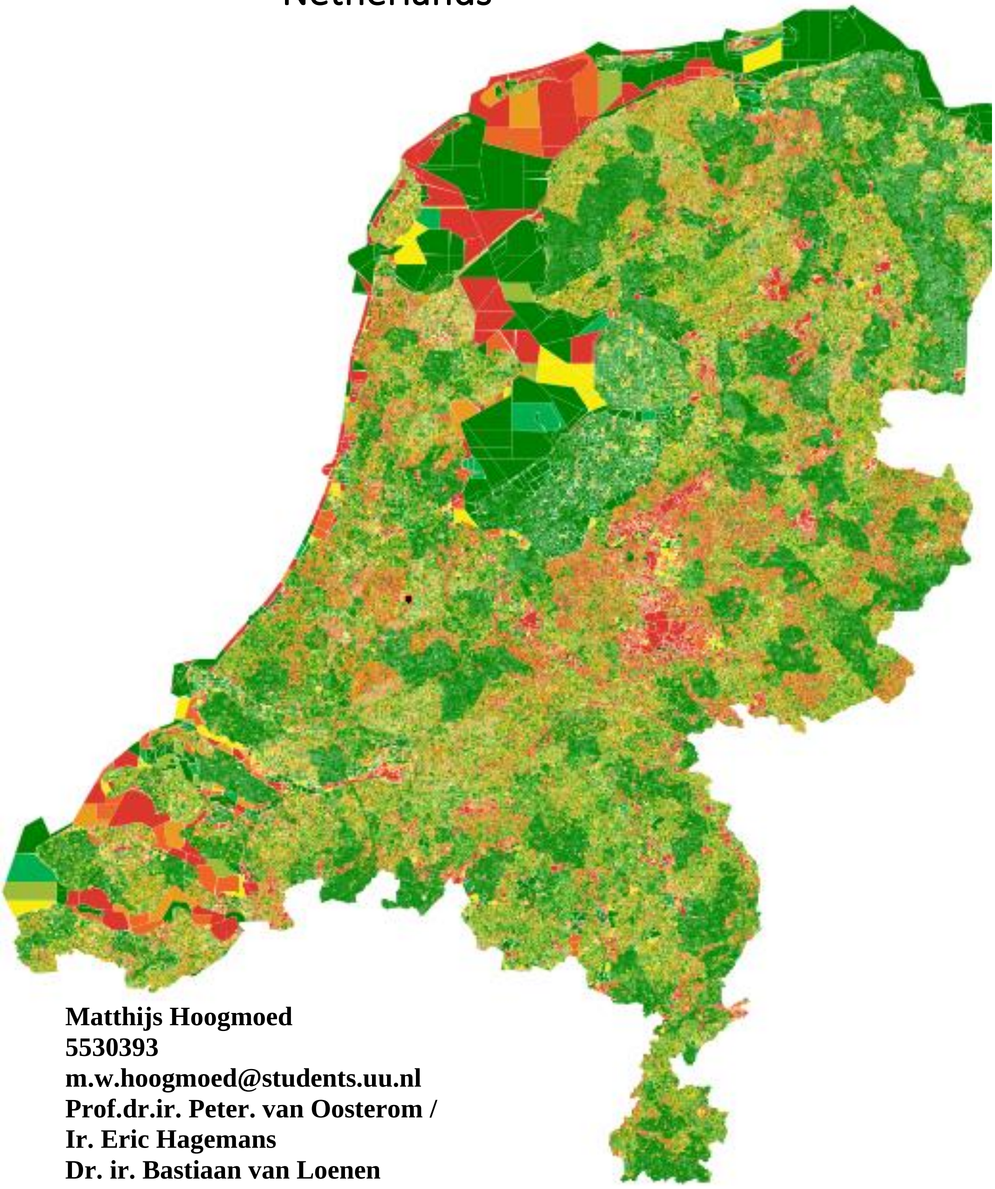
GIMA
Geographical Information Management and Applications

Visualizing the area differences of the 6th Cadastral Map of the Netherlands



Name:	**Matthijs Hoogmoed**
Student number:	**5530393**
Email:	**m.w.hoogmoed@students.uu.nl**
Supervisors:	**Prof.dr.ir. Peter. van Oosterom / Ir. Eric Hagemans**
Responsible prof:	**Dr. ir. Bastiaan van Loenen**
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Universiteit Utrecht
TU Delft
University of Twente.
Wageningen UR

Abstract

This research shows that it is possible to visualize and explore the clustering and patterns of the difference in the area of cadastral parcels in the Netherlands for the renewed (6^{th}) version of the Dutch Cadastral Map. The research itself is implemented using a literature study, design and experiments and feedback from the Dutch Cadastre. The visualization and exploration are tested on data from the current Cadastral Map (Basisregistratie Kadaster, Base Register Kadaster: BRK) and the Cadastral Map next (Kadastrale Kaart Next, KKN) pilot. However, this research focuses more on comparing the difference in the calculated and registered surface area of parcels using the current cadastral map. The visualization challenges include showing changes at individual parcel level and aggregated levels (section, municipality), showing the amount of difference (relative/absolute sizes, acceptable/not acceptable), and the direction of change (smaller, bigger). This change is relevant for many organizations: apart from Dutch Cadastre, also the owners, municipalities, water boards and provinces, as a change in the area may imply a change in value and change in taxation.

The current results show a significant preliminary difference in the area difference between parcels in rural and built-up areas in the Netherlands. Furthermore, clusters of parcels with the largest difference can be found in the natural areas of the Netherlands, which exceed the limits set by the Dutch cadastre. Furthermore, new-urban and agricultural areas show a high correlation between the registered and the calculated surface area of parcels. Lastly, the KKN pilot shows that there is a possibility of significant changes in the parcel area when the 6^{th} Cadastral Map is implemented.

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1. Introduction

The Dutch Kadaster was initially established to enhance the Dutch taxation system by measuring, processing, and archiving cadastral parcels throughout the Netherlands, resulting in a complete coverage of the entire country within the Dutch Cadastral system. However, despite this extensive coverage, the quality of cadastral measurements varies across different parcels within the Netherlands. While some parcels have been updated or corrected, others still rely on measurements dating back to the 19th century. Consequently, the current Cadastral Map does not always accurately represent the boundaries of cadastral parcels in the Netherlands. Addressing this disparity in quality, the 6th revision of the Cadastral Map seeks to utilize the cadastral field sketches to rectify the situation. However, the potential impact of this revision on the Cadastral Map and the parcel size is yet unknown (Hagemans et al., 2022).

From its inception, the Cadastral Map has served as a crucial tool for determining the parcels' relative location and contours in the Netherlands. Over time, significant advancements were made to enhance and improve the Cadastral Map through processes like digitalization (Hagemans et al., 2022). One such renovation of the Cadastral Map happened in 1998, which introduced notable enhancements compared to the existing version, primarily by leveraging the Basisregistratie Grootschalige Topografie (BGT) and the then-new technical working guide (HTW96). This approach aimed to ensure that users could effectively utilize both maps (Salzmann et al., 1998).

However, it is essential to note that despite these improvements, the renovated map did not meet the necessary criteria for precise measurements. Instead, it served as a representation or approximation of parcel boundaries, functioning as an index. Additionally, the area of cadastral parcels did not align precisely with the legally registered area. Consequently, users could potentially misinterpret or misunderstand the Cadastral Map, as the legal boundaries of parcels are only explicitly specified in the field sketches in the Netherlands and are not displayed in the Cadastral Map (Grant et al., 2020).

This risk of misunderstanding would be further amplified by the growing accessibility of web mapping applications and functionalities such as zooming and overlays. They are making it easier for users to notice discrepancies between the registered area and the calculated surface area from the Cadastral Map. Users now expect an area accuracy of at least 5 cm in 85% of the cases. The 5cm is based on the tolerance formula of $q\sqrt{a}$, in which q stands for the quality requirement in cm and stands for are (100sqm). The currently used tolerance inside the Cadastral Map is 10cm for rural areas and 5cm for urban areas (Hagemans et al., 2022).

To address these challenges, the Kadastrale Kaart Next (KKN) project was initiated to enhance the current Cadastral Map. This project combines data directly from field sketches with the existing Cadastral Map to improve its accuracy and detail. Further information about this process can be found in Franken & Florijn (2021) and Van den Heuvel (2021), as illustrated in Figure 1.1.

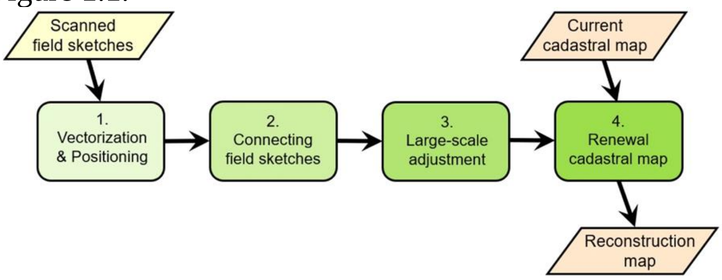


Figure 1.1: Process of creating the reconstruction map (Hagemans et al., 2022)

The resulting reconstruction map is used with local stakeholders to create the sixth version of the Cadastral Map (Hagemans et al., 2022). This process is schematically illustrated in Figure 1.2.

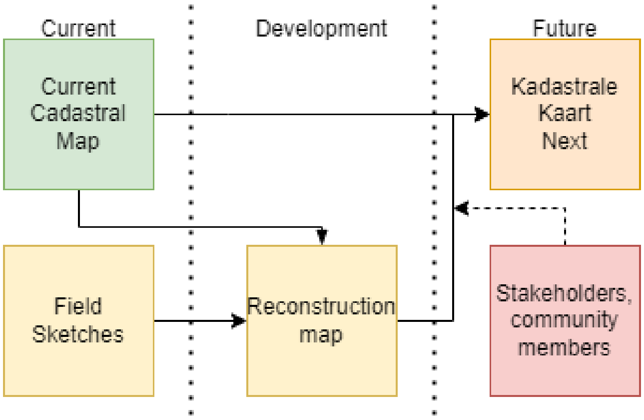


Figure 1.2: Diagram of the process of program KKN

The increased accuracy of the reconstruction makes it possible for Kadaster to recalculate the surface area of parcels in the Netherlands with such precision that it is possible also to recalculate the registered area of parcels. The recalculation is possible because the reconstruction map uses cadastral field sketches containing the official parcel measurements. Discrepancies in the registered area exceeding the limit set by the Kadaster can lead to an official change in the registered area of parcels, which changes the Waardering Onroerende Zaken (WOZ) value of parcels in the Netherlands. This, in turn, means that the sale value of a parcel changes, and because of that, the amount of taxes paid (Hagemans et al., 2022).

Such changes in size could significantly affect the feasibility of the KKN, because parcel owners might be less inclined to accept changes in boundary and area (Hagemans et al., 2022). Especially with the increasing land value in the Netherlands, it may be hard to convince stakeholders to go along with the changes if it affects stakeholders negatively (Yilmaz et al., 2015). Significant changes in registered areas might appear even more for parcels measured using older measurement techniques and tools. Because less accurate cadastral information makes large discrepancies in the area of parcels appear significantly more often (Hagemans et al., 2022).

The reconstruction map would significantly influence the implementation of the KKN. More specifically, the discrepancy between the new and old registered areas of parcels will be visible. As such, research into the level of discrepancy would give a clearer picture of the KKN's impact. Information about the parcel areas, the WOZ, differences between regions, kinds of parcels and the stakeholders will also be visible. This gives a better idea of the potential impact of the KKN implementation. Furthermore, there needs to be clear visualization and analysis of the impact of the KKN.

The knowledge about the potential impact of this research could allow for better decision-making in implementing the KKN. For example:

- It helps to prioritize certain regions of the Netherlands to implement the KKN.
- It offers different approaches for the different kinds of parcels or prepares for potential conflict with the different stakeholders.

Lastly, this research brings new insights into ways to measure, analyse and visualize the effects of a large-scale cadastral renewal on the changes in parcel size and the willingness of stakeholders in the Netherlands. This will be done using a comparative analysis of potential methods and evaluating the results, which have not been researched before in the context of the complete renewal of the map and the Dutch cadastral system. This is helping future research to find the best way to analyse the impact of large-scale cadastral changes.

1.1. Reading guide

In Chapter 1, the research provides a comprehensive introduction to the context and objectives of the study. It presents the main research question along with five specific research questions. Furthermore, hypotheses are formulated based on the research question and existing literature.

Chapter two of this research gives an overview of the theory behind this research. The chapter tries to first give an insight into the cadastral map's history, current and future state. Then the chapter goes into how cadastral parcels are measured and how the quality of this measurement is estimated and labelled. The following two sections go into the parcel value estimation and parcel owners' willingness to cooperate. The last two sections talk about how the cadastral data can be visualized and analysed and gives an overview of the conceptual model of this research.

Chapter three of this research provides the research methodology employed in the study. It starts by discussing the research area and its various dimensions, including different areas, aggregations, and scale levels considered in the research. The chapter also covers the data preparation process, outlining strategies for handling errors and outliers in the dataset. Additionally, it describes the data sources and programs utilized throughout the research. The final section of the chapter elucidates the formulas and analyses used in the study, with a visual representation of the overall research process. The overall process is visualised in Figure 3.16.

Chapter four shows the results of this research. It first gives an overview of the total area difference of the current cadastral map between the registered and calculated surface area on a national level. Then the surface quality of different parcel types is visualised and shown nationally. The following section visualises the whole of the Netherlands using Bek’s norm. This is followed up by sections about testing for spatial auto-correlation of the M’s value of parcels in the Netherlands and testing a hypothesis using Joint Univariate Local Join Count Statistics.

The next part of chapter four goes into spatial analysis of parcels on a cadastral section and cadastral municipality level. This is followed up by the results about the cadastral province of Utrecht and the municipality of Nieuwkoop to visualise and show results on a lower scale level. The last part goes into the preliminary results of the KKN pilot and the difference between the current cadastral map.

Chapter 5 comprehensively discusses the research question, drawing upon relevant literature and the study findings. The sections based on the research questions attempt to address the research questions by synthesizing the literature and research results and establishing connections with the formulated hypotheses.

In Chapter six, the thesis concludes by summarizing the most important points covered throughout the research. It reiterates the research questions, outlines the steps taken to address them, and presents the answers derived from the research findings. Additionally, the chapter may offer recommendations for future research on the topic.

The thesis concludes with a section listing the references used in the study. An appendix is also included to provide supplementary information, data, or other relevant materials supporting this research.

1.2. Research Objectives

This research will try to determine the impact of the KKN on the Dutch cadastral system, its implementation, and how it needs to be visualized. It will give an idea of what effects large-scale geometric changes have on a cadastral system and its stakeholders. This is needed before the rollout of KKN so that the Kadaster can prepare for potential problems and risks because it will potentially affect the registered area of parcels and can influence the WOZ value, which affects properties and taxes paid by private and non-private entities, which in turn can block/hinder the implementation.

It will allow the Kadaster and other organizations to better plan for an impact reduction of a complete renewal of a Cadastral Map, like the KKN. Knowing the potential impact of the KKN allows for better anticipation and decision-making for combatting potential problems. However, finding information about the impact will require extensive research and data analysis. This is exacerbated by the project being in the production phase, which means that the research needs to be done using data from a limited test pilot and extracted from the current discrepancy in the registered and calculated surface area of parcels.

Furthermore, the impact should be linked to the kind of parcels/owners because the impact can potentially differ significantly between entities like public organizations or private individuals. However, the land types and location of parcels could also significantly influence the effect of the KKN.

In short, this research aims to determine the potential impact of the KKN on the Dutch cadastral system. The impact of the KKN will be based on the registered area, the stakeholders, land types and the location of parcels; moreover, how the impact can be visualized using cartographic rules. These objectives will be operationalized in the following sub-sections as primary and sub-questions.

1.3. Research questions

The following research question and sub-questions have been created based on the research objectives. The central research question is:

How will the implementation of Kadastrale Kaart Next (KKN) affect the registered area of different categories of parcels, the WOZ value, and the willingness of stakeholders for parcel changes in the Netherlands and how to visualize the difference in area and WOZ value?

The following sub-questions have been formulated and are expanded with a brief explanation.

How will the KKN influence the registered area of the Cadastral Map?

The adaption of the KKN will change the geometry and the surface area of parcels within the Cadastral Map. When the difference between the registered and the new calculated surface area of parcels exceeds the quality set by the Kadaster, the registered size will be based on the calculated new surface area. This makes it essential to know the discrepancy between the registered and calculated surface area of parcels to identify the numbers and location of parcels impacted by a potential change in their registered area. It is also essential to know which parcels are impacted in the current Cadastral Map and how it compares to the final version of the KKN.

In what way can the parcels of the current Cadastral Map be categorised, and what are their spatial characteristics?

It is important to understand the specific types and characteristics of the parcels affected by the changes, to assess the impact of the new Cadastral Map on the surface area of parcels. This is necessary because the extent of the impact is likely to vary significantly depending on the different types of parcels involved.

In what manner may the land values of the impacted cadastral parcels change because of the implementation of the KKN?

The ground price serves as a crucial indicator for evaluating the potential effects of the KKN on the WOZ value since the surface area of the land is a key determinant of the WOZ value. By examining the ground price, which is a commonly used indicator of land value in the Netherlands, we can obtain a quantifiable measure to assess the impact of the KKN. The ground value can be traced directly from the purchase price of parcels. It is not possible to use the WOZ value directly because it’s not feasible in this research to identify the share of the surface area in the WOZ value for each of the parcels.

In which way do different stakeholders differ in their willingness to accept cadastral changes?

The stakeholders are an essential aspect of the KKN; they need to agree with the changes made in the KKN. However, stakeholders can have different requirements or limits for accepting the changes of the KKN. Governmental entities might be much more willing than private entities, meaning the degree of willingness differs between both.

What cartographic visualization should be used to visualise changes in WOZ, area, and clustering of the KKN?

Correct cartographic visualization using the cartographic principles plays a vital role in enabling professionals to accurately identify and understand the impact of the KKN on parcels. By visually representing the changes in WOZ values, areas, and clustering, professionals who rely on the Cadastral Map can enhance their decision-making processes.

1.4. Hypotheses

Hypotheses have been created based on the research questions and the theoretical framework and are listed below.

The registered area of the Netherlands is smaller than the actual calculated surface area of the current cadastral map.

The registered area of the Netherlands is likely to be smaller than the actual calculated surface area due to historical influences associated with introducing the cadastral system in 1812. During this implementation, the parcel size was smaller than the measured size to facilitate the ground-based taxation system. Consequently, any disparities between the registered parcel area and the actual calculated surface area depicted in the cadastral map indicate the manner of adjustments to the total parcel area with the implementation of the KKN (Kadastrale Kaart Next). Based on this, the following null and alternative hypotheses are formed:

H0: There is no statistically significant difference in the total area of parcels.
H1: There is a statistically significant difference in the total area of parcels.

Rural areas differ more than the built-up areas between the registered and calculated surface area than the built-up areas.

There is a potential difference between the area of built-up and rural areas because of differences in the precision requirements and the number of remeasurements (Salzmann et al., 1998). Rural parcels have a norm of $10\sqrt{a}$ and built-up areas $5\sqrt{a}$, which would indicate that built-up areas are lower (Van Den Heuvel et al., 2022). Based on this, the following null and alternative hypotheses are formed:

H0: There is no statistically significant difference between rural and built-up parcels.
H1: There is a statistically significant difference between rural and built-up parcels.

Changes in a parcel's surface area likely mean that another surrounding parcel's surface area changes opposite, to compensate for the change in the surface area.

Based on the understanding that changes in a parcel's calculated surface area often correspond to opposite changes in the calculated surface area of surrounding parcels and that changes in parcel size affect the parcel's boundaries (Polman & Salzmann, 1996), the following null and alternative hypotheses are proposed:

H0: There is no significant spatial relationship between a change in a parcel's surface area and the surface area of its neighbouring parcels.
H1: A significant spatial relationship exists between a change in a parcel's surface area and the surface area of its neighbouring parcels.

2. Theoretical Framework

Understanding the effects of the KKN will require an analysis of the potential impact and theory about cadastral renewal and its effects. The theoretical framework will, as such, be based on the research questions. For this, the chapter will try to list all relevant literature and information in the following subchapters: history and status of the Cadastral Map, implementation of the KKN, measuring of parcels, parcel types, WOZ, the willingness of parcel owners and lastly, topography.

2.1. History and status of the Cadastral Map

The Dutch Cadastral Map is interwoven with the history of the Dutch Kadaster, wherein the Cadastral Map was influenced throughout its history by decisions and developments of the Kadaster and the Dutch government (Hagemans et al., 2021), which means that to explain the current status of the Cadastral Map, the history of the Kadaster and the history of the Cadastral Map need to be explained.

2.1.1. The early history of the Dutch Cadastral Map

The Dutch Cadastre was founded in 1811 by the directive of Emperor Napoleon to improve taxation (Nijstad, 1982). The cadastre would be based on the land readjustment of the existing French cadastre. Earlier local works of the Dutch cadastre were put aside due to differences in measuring and quality. This made necessary a complete remeasurement of the Netherlands, based on the Recueil Méthodiquc. The measurement was done between 1812 and 1832. The process was sped up by implementing the so-called 'Circulaires van Gericke' (Gericke circulars). The implemented changes of the Circulaires meant that the topographic boundaries would only be included if they matched the legally registered boundaries (Kruizinga & van Doornmalen, 1997).

The process of measuring boundaries required four pre-steps. The municipality boundaries needed to be measured; there needed to be a geometric foundation, dividing municipalities into multiple sections and designating plot boundaries. Maps of these sections are also called Minuutplannen ('Minute plans') (Nijstad, 1982). This process, which includes measuring boundaries, was decentralized for each department by an "Ingenieur-verificateur" ('Engineer verificator'). The Ingenieur-verificateur had supervised 5 to 12 surveyors first class under him. The first-class surveyors again supervised second-class surveyors working under them (Kruizinga & van Doornmalen, 1997).

Border disputes between municipalities needed to be solved by these authorities. The Ingenieur-verificateur measured the municipality boundaries with help from mayors and two other designators. The mayors and designators indicated the boundaries of their municipality, which the Ingenieur-verificateur would then use to create a proces-verbaal (report) and the measurements of municipality boundaries. Exclaves of municipalities would be included in the surrounding municipality boundaries. This means one municipality could have multiple cadastral municipalities, which is becoming even more like the "gemeentelijke herindeling" (municipality reorganization). This measurement also made areas outside the borders of existing municipalities outside the Cadastral Map less accurate (Kruizinga & van Doornmalen, 1997).

The following step was the creation of sections on the map. These sections were given a letter and name based on the local area. The sections were as much split on boundaries like rivers, roads, and dikes. The section boundaries were also described in detail (Kruizinga & van Doornmalen, 1997).

The next step was creating a local geometric foundation based on local triangulation (Hagemans et al., 2022a). Triangulation was locally done using the closest or most crucial church tower. New points in the network would be created using flags placed one to two kilometres from the centre point. Each node in the network would get its coordinates calculated and recorded. This process was repeated until a complete network could be made (Kruizinga & van Doornmalen, 1997).

The local triangulation system was imperfect because of accuracy problems and the connection to other local systems. These problems were solved by implementing a national coordinate system between 1888 and 1904 with the Rijksdriehoeksmeting (RD). However, not all local measurements would be updated using the national grid until around 1928. Furthermore, maps would only be updated with the national grid when an update was required (Kruizinga & van Doornmalen, 1997).

The previously selected sections were then used to find the owners of parcels in combination with the "verpondingsregisters". The resulting list of owners inside the parcels would be used to contact all owners. These, in alphabetical order, needed to show the boundaries of their parcels to a surveyor and a local designator familiar with the area. Not every owner would cooperate with this process because they did not know the importance or were afraid of having to pay more taxes. In such cases, the boundaries could be made with the help of third parties or one-sided measurements (Kruizinga & van Doornmalen, 1997).

The measurements of parcels were done with triangulation and a metal chain. Measuring a straight boundary was done using only two points and with an accuracy of 1 meter in rural areas and 0.5 meters in built-up areas. Curved boundaries were measured using the most prominent edges of the curve. Surveyors did not use control points for all the measurements, making discrepancies of 10-40 meters possible. The measurements were stored in the local field sketches (Kruizinga & van Doornmalen, 1997).

Area size within parcels was calculated using triangles, allowing the surveyor to find the size of parcels. The surveyor would do this by recording all the required boundaries of the triangles and then dividing the total result by two. The final result was as accurate as the used scale of the map. The result also did not need absolute accuracy because it was only used for collecting ground-based taxation (Kruizinga & van Doornmalen, 1997).

The final result was checked using verification lines, which would go across multiple parcels. The intersections between the line and the parcels would then be checked to see if there was a difference. Significant differences would mean that the measurements needed to be redone. However, this did not always help with the accuracy of the map. Sometimes, there would be a kink in parcels where the verification line intersected (Kruizinga & van Doornmalen, 1997). The resulting fieldworks would only consistently be saved to an archive from the year 1878. Fieldworks before 1878 were not always consistent and or stored correctly (Hagemans et al., 2022).

The abovementioned process did not deliver the accuracy required for the increasing need for up-to-date knowledge and high precision. From 1860, Minuutplannen of low quality were improved by directly pasting the survey information of new field sketches on the Minute plans and then combining it. However, this did not increase the overall quality of the map. The implementation was complex because of mismatch problems between other parcels in the Minuutplan and the field sketches themselves. This meant that the only solution was a complete remeasurement of the parcels. Because of costs, remeasurement was only done for Minute plans with low quality and in cases of significant changes in land use. These changes are large-scale changes in land use, like urban expansion, land consolidation or municipal redistribution (Kruizinga & van Doornmalen, 1997). Areas like old towns, however, are not continuously updated and remeasured to a higher standard (Hagemans et al., 2022).

The development of the Cadastral Map was improved continuously with standardization and better measuring methods. The standardization started initially with the work of LCJA van Aken in 1863, who created methods for remeasurements and testing. These methods were improved and standardised in the first Handleiding voor technische werkzaamheden (HTW) in the year 1902. New methods and instruments, like the Rijksdriehoeks-meting (RD), meant a new version of the HTW was made in 1938. This was followed up by the HTW of 1956 and the current version of HTW in 1996 (Polman & Salzmann, 1996). An overview is given in Figure 2.1.

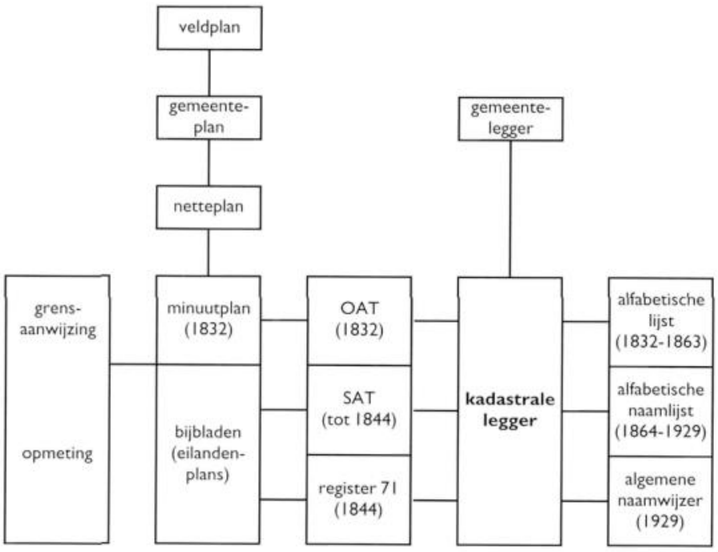


Figure 2.1 Relationship between the original cadastral sources (Kruizinga, 1997)

2.1.2. Digitalization of the Dutch Cadastral Map

In the first iteration, the Cadastral Map was an analogue map showing parcels' relative locations and shapes in the Netherlands. Numbers and letters link to the relevant field sketches of the parcels, which, if needed, could be acquired from the archive of the Kadaster, which means that a physical copy needed to be acquired. Furthermore, the map was based on fieldworks of differing quality and measurements (Hagemans et al., 2022).

The digitization of the Cadastral Maps was finished in 1994. However, it still had the problem of having sources of differing quality, and the map did not meet the requirements set by the Kadaster. The Kadaster wanted the map to fit a strict quality specification so their customers could use it for large-scale mapping activities and geometric reference of administrative data. Furthermore, users should be able to use the map correctly in conjunction with the large-scale base map, the 'Basisregistratie Grootschalige Topografie' (BGT). This required a complete harmonization process between the BGT and the Cadastral Map, ensuring the borders overlap. The border overlap was implemented to prevent user confusion about the location of the parcel boundaries in relation to the BGT (Salzmann et al., 1998).

This process was a complete renovation of the map, meaning it needed to be set to the following requirements:

- The geometric quality needed to be $40\sqrt{2}$ cm and $20\sqrt{2}$ cm in rural and built-up areas, respectively.
- Completeness: the map should contain all parcels, roads, main buildings, street names and house numbers.
- Attribute accuracy: the map should contain the postal codes for each of the parcels.
- Consistency: the Cadastral Map should be structured in a coherent way.
- Up-to-datedness: the map needs to depict the current legal situation.

Furthermore, the digital map would be a seamless map covering the whole of the Netherlands and have a scale of 1:1000 and 1:2000 for built-up and rural areas, respectively (Salzmann et al., 1998). Renovating was done using a set of tools, which could change based on the source data, meaning there was no fixed procedure for the renovation. Furthermore, there were three other limiting factors to the renovation. The geometry of the BGT could not be changed, buildings were only added as references to the Cadastral Map, and the quality of the Cadastral Map needed to be described (Salzmann et al., 1998).

The renovation consisted of multiple steps: prepossessing selection and transformation, testing and connection adjustments, interpolation, reconciliation, and post-processing. The order of steps was always the same, but some steps can be skipped for high-quality data. The described steps allowed for a higher quality map (Salzmann et al., 1998), which has a registered relative precision of 40 cm for rural and 20 cm for built-up areas. The map renovation was completed in the year 2006 (Hagemans et al., 2022).

2.1.3. Current Dutch Cadastral Map

As described earlier, the Cadastral Map shows the relative location and geometry of parcels in the Netherlands. The Cadastral Map was harmonised so that buildings, house numbers and street/water names were also incorporated into the Cadastral Map. The map was furthermore included in one of the primary Dutch registries of the Netherlands, called the Basisregistratie Kadaster. The data was now also standardized using a model set by the Kadaster, allowing for interoperability and standardization (PDOK, 2022).

2.1.4. Visualization

Visualization of the Cadastral Map uses a set of rules in the HTW. Firstly, the map shows the boundary lines of parcels in the Netherlands as black lines. The parcel boundaries contain the parcel number and show the relative location of the parcel boundaries. However, the boundaries in the Cadastral Map are not the legal boundaries of the parcels because they are stored inside the deeds of the parcels. However, the Cadastral Map aims to fit the legal boundaries as much as possible (Hagemans et al., 2021).

Buildings and house numbers were added to improve the useability and readability of the map. Red lines in the map are used to visualize the main buildings' borders and contain the house number related to the building. The outline of the buildings is based on the BGT, which uses stereographic imagery to visualize the outline. The name of waterways and roads is added to the map for the same reason (Salzmann et al., 1998). An example of part of the current Cadastral Map is shown in Figure 2.2.

Figure 2.2 Example of a part of the Cadastral Map

2.1.5. Data model and LADM

Every parcel and building in the Cadastral Map contains a set of attribute data. This attribute data gives more information about the polygons themselves. Attribute data is based on a data model set by the Kadaster itself. The data model gives the specifications and requirements for each attribute and polygon and uses a UML structure (Kadaster, 2022). The Cadastral Map's data model for the fourth version is shown on the Digitale Kadaster Kaart (DKK) developer site and is also shown in Figure 2.3 (Kadaster, 2022).

The UML diagram shown in Figure 2.3 shows the structure and relations of the current digital Cadastral Map. It shows the relationship between the BGT and the DKK, wherein the DKK inherits the data from the BGT. The DKK: BGT contains the pand class containing the house number value and the Openbareruimte class containing street and waterway name labels. The DKK contains the Cadastral boundary and parcel class (Kadaster, 2022). The DKK is an integral part of this research because it shows the primary data model used in this research. The DKK classes are shown in Table 2.1.

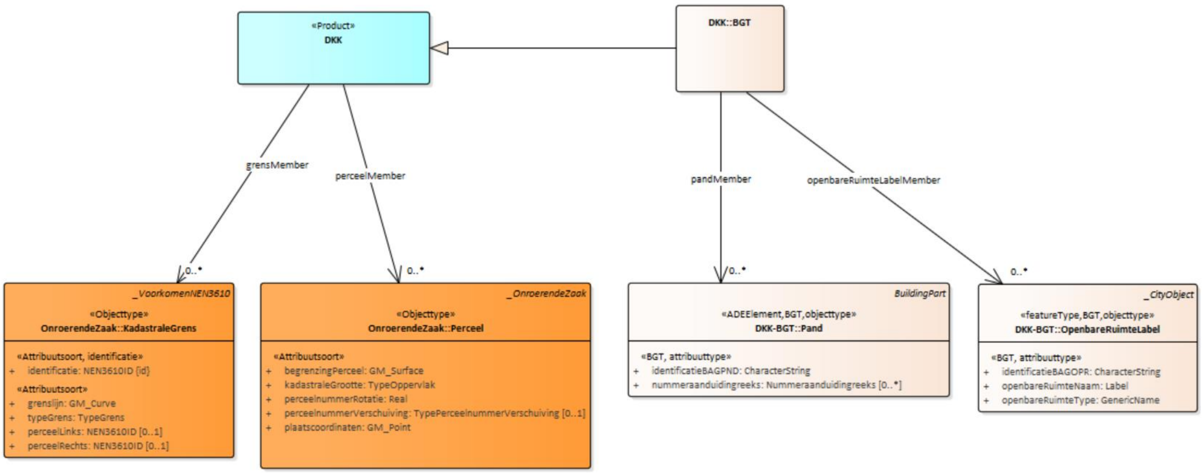


Figure 2.3 Class diagram of the BRK

The cadastral classes are divided into the cadastral boundary and parcel classes. Each class contains geometry and attributes related to its location and characteristics. See Table 2.1. A short description of each attribute in the classes is given in Tables 2.3, 2.4 and 2.5 (Kadaster, 2022). The history class is linked directly to the cadastral boundary and parcel classes, as shown in Table 2.2.

Table 2.1 Cadastral Classes

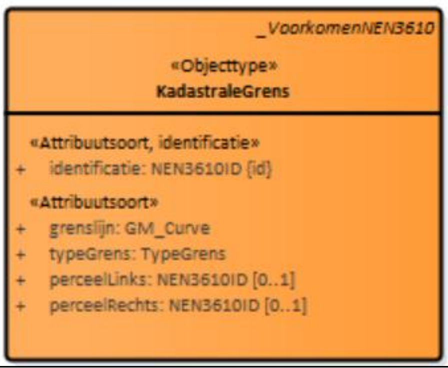
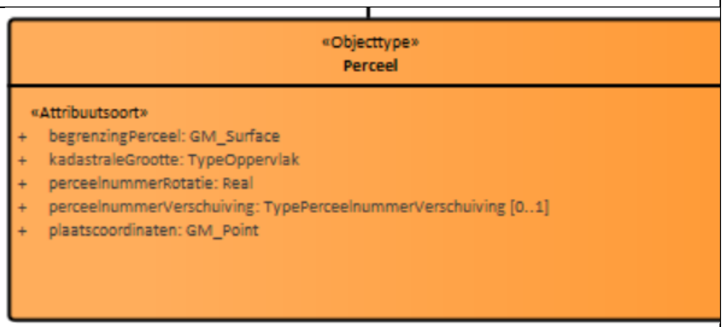
Cadastral boundary	Parcels
 	

Table 2.2 Cadastral history class

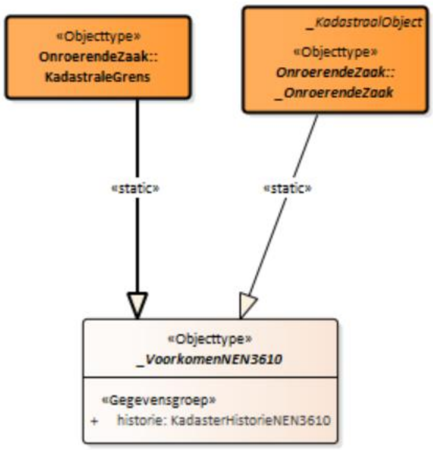
<table>
<tr><th>Relation cadastral history</th><th>Cadastral history class</th></tr>
<tr><td>
</td><td>
</td></tr>
</table>

Table 2.2 Attributes of the Cadastral border class

Attribute data Kadastrale Grens	Description
Identificatie	Unique identifier of the object within the cadastre
Grenslijn	The parcel boundary, Contains a GML LineString of the border
Typegrens	Presents the type of border, which can be definitive, temporary, or administrative
Percee|links	Gives the parcel situated to the left of the parcel
Percee|Rechts	Gives the parcel situated to the right of the parcel

Table 2.4 Attributes of the Data Perceel class

Attribute data Perceel	Description
BegrenzingPerceel	Contains the GM_Surface attribute
KadastraleGrootte	Contains the established parcel size by the Kadaster
PerceelnummerRotatie	Determines the rotation of parcel numbers
PerceelnummerVerschuiving	Give the parcel number offset
Plaatscoordinaten	Gives the coordinates of parcels, as GM_Point

Table 2.5 Attributes of the History class

Attribute data KadasterHistorie	Description, datum uses the yyyy-mm-dd: hh:mm: ss.fff format
beginGeldigheid	When the object was live
eindGeldigheid	When the object was put offline
tijdstipRegistratie	When the object was registered to the system
eindregistartie	When the object was deregistered on the system
volgnummer	Tracking number
statusHistorie	Three possible options for history; status, correction, audit and valid

2.1.6. Program Kadastrale Kaart Next

A new development of the Cadastral Map is executed/performed in the KKN program. The project is meant to create a new revision of the Cadastral Map. This map revision is meant to create a Cadastral Map of higher accuracy and better geometric quality, using data directly sourced from historical fieldwork. For boundaries and points, the program expects to achieve a precision differential of 5% in 85% of the cases. This will make the Cadastral Map much more similar to registered boundaries inside the field sketches. This is needed to prevent incomprehension and inconvenience among the users if they are unaware of the history and methodology behind the current Cadastral Map and its influence on the position of boundaries and the area (Hagemans et al., 2021, 2022c).

The new Cadastral map will be a complete renewal of the current Cadastral Map to combat the inherent inaccuracies and geometric quality issues in the current Cadastral Map. The Cadastral Map should be rebuilt using the source data contained in the field sketches and survey documents. Processing the 5.5 million (Franken & Florijn, 2021) field sketches by hand would not be cost-effective for the Kadaster because of person-hour requirements involved. As such, the Kadaster has created a new program that is meant to automate this process as much as possible (it is impossible and not desirable to automate the process completely)(Hagemans et al., 2021).

It is impossible to update the current Cadastral Map directly with the data from the field works and survey documents. Furthermore, the data cannot be integrated immediately into the Cadastral Map because of legal and data reasons. This will require a process containing ways to vectorize, position, connect, and make large-scale adjustments. The process is shown in Figure 2.4 (Hagemans et al., 2021).

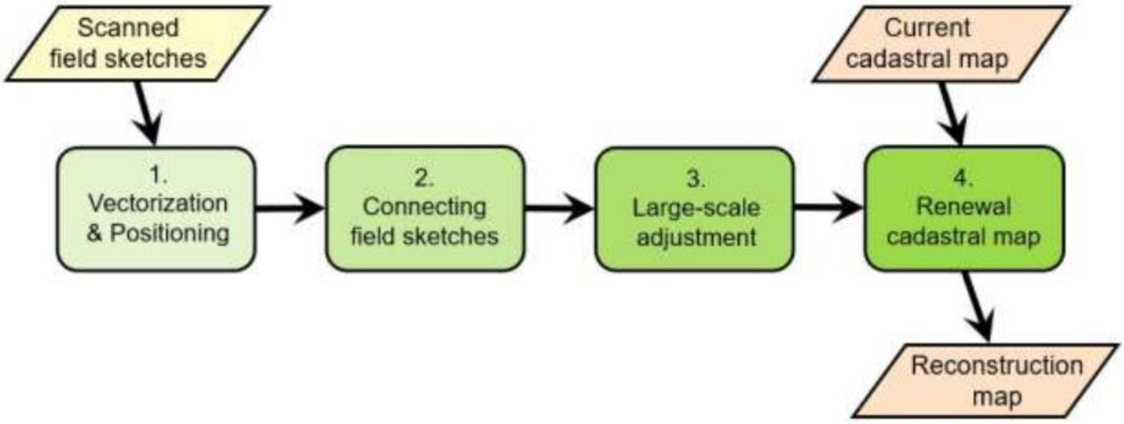


Figure 2.4 Process of the KKN program

The JPEG field-work data should first be digitized and converted to a machine-readable format, which will be done using the AI-based "VeCToR" solution to vectorize, position and link parcels. Machine learning reads parts of the digitized fieldwork, line and points, measurements, parcel numbers, buildings, and symbols. The machine learning algorithm will continuously be improved and tweaked to improve the model detection of the elements, to prevent false positives or missing data. The field sketches and parcels will be positioned by an edge-matching algorithm, which uses geometry in the BGT (Van Den Heuvel et al., 2022). Linking different field sketches is done by finding close or overlapping points (Franken & Florijn, 2021).

Further network adjustments are made using statical testing and linking the vectorized data to the RD-coordinate system. The earlier linked points of the field sketches are connected to coordinates and are validated and adjusted. Clusters of fieldwork are again validated and adjusted, made possible by the increase in the number of observation points. Coordinates are also adjusted in the cluster of fieldwork based on GPS reference points (Van Den Heuvel, 2021).

Local networks of fieldwork need to be linked to large-scale networks. This step requires a different approach because of the billion existing observations and 500 million variables. The 500 million variables make it not feasible to make the adjustments on the fly, when using the MOVE3 program of the Kadaster and requires a new solution able to process all the data, a solver capable of finding a solution for the network and giving the corresponding statistics fast enough. These large-scale networks can then be directly combined with the overall network or have points with multiple coordinates (Van Den Heuvel, 2021).

The point map resulting from this process is used together with the current cadastral map to determine which points are edges of a boundary and which are boundary corners. Also, a relationship is established between the points of the current cadastral map and the process results. The resulting relationship is then used in conjunction with both maps' quality information to update the nodes' positions on the cadastral map. This step is necessary because of potential discrepancies between both maps. Possible discrepancies are listed below (Franken & Florijn, 2021).

- Parcel boundaries can disappear due to the merging of parcels.
- Building polygons can change during the creation of the reconstruction map, making it hard to link both maps.
- Not all boundaries are registered in the cadastral system; for example, fieldworks before 1878 were not always archived.
- Extra points resulting from the large-scale adjustments, which do not correspond to any feature.
- The positional accuracy of the Cadastral Map is significantly lower.

The project's last step is implementing the reconstruction map's results into the next-generation cadastral map, Kadastrale Kaart 6 (KK6). The implementation will be a gradual process of 'smoothing.'. There are three required measures. Firstly, the local government should be informed and involved in the project. Secondly, the general public needs to be made aware of the actual and current quality of the map. Lastly, the individual users have to be guided in the case of questions or problems. This might be the case when the changes in geometry cause the registered parcel size to change (Hagemans et al., 2021).

Next, for the introduction of the KKN, changes have been proposed to improve the data model of the Kadaster by implementing the Netherlands Survey and Representation Data Model (NLSRDM), which is based on the Land Administration Domain Model (LADM) standard. The new model will allow boundaries, points, and parcels to be cadastral objects. Storage of extra information about the elements will be made possible. For example, objects can be linked directly to their survey document, the type of data carrier, topological relations between the cadastral and reconstruction map, and history model/ timestamps (Hagemans et al., 2022).

2.2. Calculating the parcel area

Area size calculations of parcels are a process within the cadastre needed for calculating the monetary value of a parcel. Remeasurement of area is only done in case of parcel boundaries or cadastral renewal changes. The area calculation tries to find the error between the registered and calculated surface area, ensuring it does not exceed the tolerance. The calculation should be done with controlled measurements based on precise coordinates and measurements contained within the fieldwork or are new measurements. The measurements themselves are done using the following measurement scales' hectaren' (1000 m^2), 'aren' (100 m^2) and 'centiaren' (1 m^2) (Polman & Salzmann, 1996).

The area difference is calculated using points linked to precise coordinates in the RD coordinate system. This means that parcel areas with no RD coordinates need to be linked to the closest area containing precise enough coordinates or be remeasured. The following step is determining the contour of the new parcel and using it to calculate the total area. The next step is comparing the size of the deed and defunct parcel size with the calculated parcel area. Results from this comparison are then used to determine if there needs to be a 'recificatie' and 'redressering' of the area based on set tolerances. Recificatie happens when the area of the deed of transfer exceeds the tolerance set by the Kadaster, updating the specified area in the deed with the calculated one. Redressering happens when the area exceeds the registered area stored within the Kadaster, updating the registered area values stored by the Kadaster. The process is shown in Figure 2.5 (Salzmann et al., 1998).

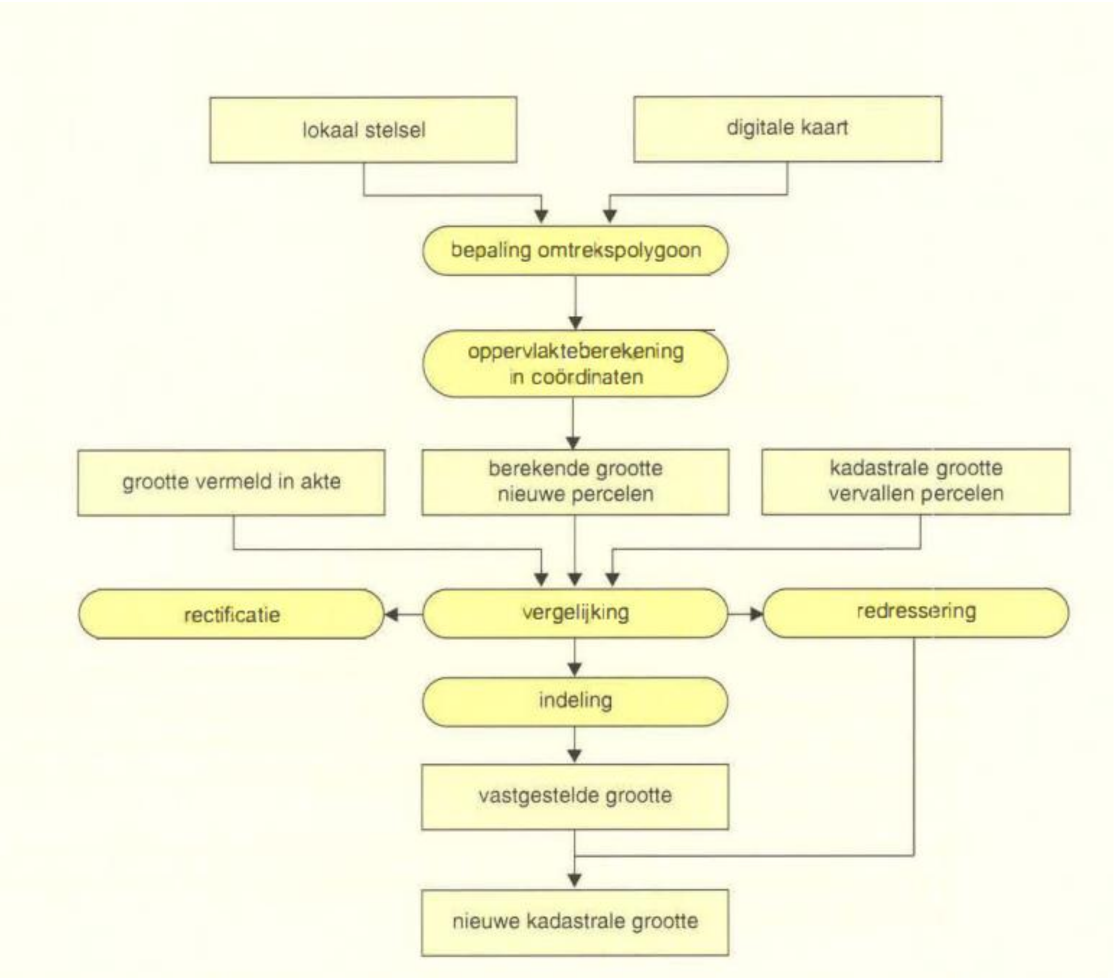


Figure 2.5 The process of calculating the area of parcels.

2.2.1. Areas size formula

The area calculation of the Kadaster is specified in the Handboek Technische Werkzaamheden 96 (HTW96). HTW96 specifies the methodology used by the Dutch Kadaster and is the basis for the current Cadastral Map and the measurements. The method uses the RD coordinate system(Polman & Salzmann, 1996).

HTW96 specifies the following formula for measuring the area of parcels using the contour polygon, where a = Aren = 100m^2

$$a = \frac{1}{200}\sum_{i=1}^{n} x_i(y_{i-1} - y_{i-1})$$

with the coordinates $x_i \cdot y_{i-1} \cdot y_{i+1}$ of the contour polygon in meters.

2.2.2. Geometric quality of the area

Measuring the difference in area between the registered area and the calculated size is possible with different formulas. However, the data limitations of the Kadaster limits the possible methods. For example, not every point or object on the map has a quality identification or is based on terrestrial observations. The Kadaster is limited to only two readily available values per object when looking for the quality of the area calculations: registered area and calculated area (Hagemans et al., 2020).

The Kadaster formulas for determining the quality of the area calculations are described in HTW96(Polman & Salzmann, 1996) and the report by Hagemans, Liem, Grift, Schepens & Haselen (2020). HTW96 defines three possible formulas to determine the standard deviation. The HTW96 assumes that the registered area is correct and the calculated area deviates.

This first formula expects high-quality point data, only available in the second version of the Kadastrale Kaart 2 (KK2) (Salzmann et al., 1998).

l = The nodal line length in meters,
σ_i^2 = the point precision in cm^2,
d_i^2 = idealization precision in cm^2.

$$\sigma_a = \frac{1}{200}\sqrt{\sum_{i=1}^{n} l_{i-1,i+1}^2(\sigma_i^2 + d_i^2)\,[ca]}\,, l_{i-1,i+1}^2 = (x_{i+1} - x_{i-1})^2 + (x_{i+1} - x_{i-1})^2$$

The second formula is less precise than the first one, but it can be used to calculate the error of rectangular parcels. This formula applies to 99% of the parcels (Hagemans et al., 2020).

σ_a = the area in are =100m^2
v = the length-to-width ratio in are,
c_0 = the point precision in cm^2,
d^2 = idealization precision in cm^2.

$$\sigma_a = \frac{1}{10}\sqrt{(c_0 + d^2)^2(v - \frac{1}{v})^a}$$

The last formula can be used to calculate the error based on square parcels and is currently the most used one by the Kadaster. However, this formula is too rough for the correct analysis of area quality (Hagemans et al., 2020). The values are shown in Table 2.6.

Table 2.6 Tolerance when the standard deviation is not known.

Precision class	Tolerance (centi-are = m^2)
Terrestrial	$\sqrt{a}$
Graphical, built-up areas	$5\sqrt{a}$
Graphical, rural areas	$10\sqrt{a}$

Hagemans et al. (2020) specify two formulas based on the second formula of the HTW96. The second formula was chosen because of the assumption that almost all the parcels are rectangular and that no detailed terrestrial information is currently available. This formula also considers that the registered and calculated area could be mismatched (Hagemans et al., 2020). Implementing the LADM in the current data model of the Kadaster could make the first formula feasible (Hagemans et al., 2022).

The first formula is similar to the second formula described in the HTW96.

v = length-to-width ratio,
$\sigma^2_{grens,\ grootte}$ = the boundary area in cm^2,
$\sigma^2_{grens,\ oppervlakte}$ = the boundary area in cm^2
opp = the registered area in are.

$$\sigma_{grootte.vearschil} = \frac{1}{10}\sqrt{\left(\sigma^2_{grens,\ grootte} + \sigma^2_{grens,\ oppervlakte}\right)\left(v + \frac{1}{v}\right) opp}$$

This formula shows how the length-to-width ratio can be derived from a rectangular polygon's contour and area. Omtr is the perimeter of the polygon in meters, and Opp is the area in are.

$$\left(v + \frac{1}{v}\right) = \frac{Omtr^2}{4 \cdot Opp} - 2$$

Mark Beks proposed a new formula that combines the area and the length-to-width ratio to calculate a normalized metric number. The number can directly be used in algorithms and does not need to be calculated again. Lastly, the formula makes use of m^2 instead of are.

The formula makes use of the following variables Opp_{krt} = is the calculated area in m^2 and GRT_{BRK} is the area based on the registered area.

$$M = \frac{Opp_{krt} - Grt_{BRK}}{\sqrt{\left(v + \frac{1}{v}\right) \cdot Opp_{krt}}}$$

This formula calculates the Beks norm used to test the normalized M result. (Hagemans et al., 2020).

$$N_{Beks} = 2 \cdot \sqrt{\left(\sigma^2_{grens,\ grootte} + \sigma^2_{grens,\ oppervlakte}\right)}$$

2.2.3. Labelling the Geometric quality of parcels

There have been multiple attempts to quantify and label the quality of parcels and boundaries in the Netherlands using quality codes. For example, the precursor to the BRK, landmeetkundig kartografisch informatiesyteem (LKI) contained quality labels. However, these codes were error-prone due to the manual registering of the data. The error-prone nature of the old codes meant that these old codes were dropped altogether in the BRK. However, there is still a need for a classification method to specify the usefulness and quality of parcels and boundaries in the Cadastral Map (Hagemans et al., 2020).

The need for quality identification of boundaries meant that a new quality description was needed. Resulting in the first version of the geometric quality description "Geometrische kwaliteitsbeschrijving". The geometric quality description allows listing the parcel's potential use cases and boundary data. Furthermore, the new method always assumes the worst case when selecting the class to prevent overestimations of quality (Hagemans et al., 2020). Hanus et al. (2020) describe a similar system based in Poland, which uses a reliability coefficient to measure the quality of parcels.

The system is based on specifications set in the HTW96 and is visualised using a classification system similar to energy labels. The highest possible quality is given an A, and the worst case is a G. The letters are linked to a decision tree. Current parcels and boundaries are now primarily situated in the category of D and E, according to the Kadaster. They furthermore predict that the quality of parcels will decrease with the implementation of the KK6. Table 2.7 shows the proposed classification system of the cadastral for point and boundary quality (Hagemans et al., 2020).

Table 2.7 Geometric quality of points and boundaries

	Label	**σ_{punt}** (cm)	**$(\sigma_{punt})^2$ = c_0**(cm²)	**Strook-breedte** (+/- cm)	**Bereik σ_{punt}** (cm)	**Verwijzing naar HTW en/of LKI-codering**	**Nadere omschrijving en verantwoording**
Terres-trisch lokaal	**A**	2	4	4	0 – 3	GPS-kernnet (blz. 57)	aantoonbare1-op-1-kwaliteit (!) stedelijk gebied
Terres-trisch norm	**B**	5	25	10	3 - 7	Terrestrisch grondslagelement (blz.58)	Terrestrische kwaliteit (HTW-96), 1-op-1-kwaliteit universeel
Terres-trisch landelijk	**C**	10	100	20	7 - 15	Fotogr. stereo-kartering, 1:3000 (blz. 59) / LKI klasse 3	1-op-1-kwaliteit landelijk gebied
grafisch bebouwd	**D**	20	400	40	15 - 30	Vereiste kwaliteit kad. kaart (blz. 53) / LKI klasse 4	Grafische kwaliteit (HTW-96) stedelijk gebied
grafisch landelijk	**E**	40	1600	80	30 - 60	Vereiste kwaliteit kad. kaart (blz. 53) / LKI klasse 5	Grafische kwaliteit (HTW-96) landelijk gebied
historisch	**F**	80	6400	160	60 - 250	LKI klasse 6	Schatting kwaliteit op basis van kaartschaal 1:2500
grove fouten/ onbekend	**G**	-	-	-	250 - ∞	LKI klasse 7	Ook te gebruiken voor voorlopige & admin. grenzen

A classification system has also been made to differentiate between the registered and calculated areas. The results from the classification should not be used for identifying parcel quality because the current included point data is not sufficient for describing the quality of parcels. Furthermore, the process does not consider the effect of other parcels connected to it. However, the classification can still be used to determine the difference in areas (Hagemans et al., 2020).

The classification itself uses the earlier mentioned M-value based on the BEK's norm. The label name is based on the range of A – G, where A is the highest value, G is the lowest, and the OD part stands for "oppervlaktedelta", meaning area delta. The ODA value is created in preparation for the reconstruction map and the KKN. The classification also contains two possible scenarios for the difference in the area. This is needed because only the area and length-width ratio are used in this research. This means multiple explanations may be possible for a particular M-value like the registered area could have been determined from the calculated area or sourced from high-quality measurements (Hagemans et al., 2020). The classification is shown in Table 2.8.

Table 2.8 Classification method for parcel size differences using Bek's norm.

Perc. label	$C_{0,\ size}$ (cm2)	$C_{0,\ surface.}$ (cm2)	Assumed situation parcel /indication standard	Alternative situation parcel
ODA			Both values are of high quality, with size determined from measurement figures, the map local 1-to-1 quality.	Both values are highly correlated (e.g., size determined from the same map)
	A (4)	A (4)	**N1: Standard terrestrial local:** 1-to-1 quality	**Beks norm / M-value: 0,0566**
ODB			Both values are of high quality, with size determined from measurement figures, the map 1-to-1 quality.	Both values are highly correlated (e.g., size determined from the same map)
	A (4)	B (25)	**N2: Standard terrestrial absolute:** 1-to-1 quality	**Beks norm / M-value: 0,1077**
ODC			Size determined from measurement figures (B); map improved graphical quality (C)	The reverse of the assumed situation
	B (25)	C (100)	**N3: Norm graphically improved**	**Beks norm / M-value: 0,2236**
ODD			Meets the urban area standard: size determined from measurement figures (BD) or a correct map (DB)	The reverse of the assumed situation
	B (25)	D (400)	**N4: Norm graphically urban: ~ 5√a norm** urban area	**Beks norm / M-value: 0,4213**
ODE			Meets the rural standard: size determined from measurement figures (CE) or a correct map (EC)	The reverse of the assumed situation
	C (100)	E (1600)	**N5: Norm graphic rural / redress urban: ~ 10√a norm** rural area	**Beks norm / M-value: 0,8246**
ODF			Does not meet standard norm: either size, map area or both do not meet. norm	The reverse (CF or FC) or both have large errors.
	C (100)	F (6400)	**N6: Norm relief rural: ~ 20√a norm** rural area	**Beks norm / M-value: 1,612**
ODG			Gross errors in one or both numbers	No alternative

2.3. Estimation of parcels value

The annual valuation of properties in the Netherlands is an essential part of the property taxation process, which includes the size of parcels. The value of parcels influences the amount of property taxes to be paid by the owners, meaning that the size of the parcels is vital for estimating the valuation of the properties. Each year, a new appraisal is done of the current value of properties and then used to determine the new taxation amount. The valuation of properties is done by the Dutch municipalities (Kara et al., 2019). Other government agencies also use the valuation of properties for other tasks, like mortgage lending, social housing and fighting fraud.

2.3.1. WOZ

The valuation of properties in the Netherlands is the so-called WOZ and is managed by the Dutch Waarderingskamer. The WOZ itself is based on the definition set by the International Valuation standard: "the estimated amount for which an asset or liability should exchange on the valuation date between a willing buyer and a willing seller in an arm's length transaction, after proper marketing and where the parties had each acted knowledgeably, prudently and without compulsion" (Berkhout & Hordijk, 2010). The definition illustrates the need for correct calculation of the WOZ value based on the property's current market value, which is essential for residential properties with a taxation rate of 0.1% to 0,2% of the value and 0,2% to 0,4% for non-residential properties (Kara et al., 2019).

Appraisal of the WOZ value of properties is done using market data and object characteristics. The market data is based on variables like sale data and information from the Dutch base registries. Object data includes characteristics like parcel size, property type, size, and year of construction (Kathmann & Kuijper, 2018). A list of data sources is illustrated in Tables 2.9 and 2.10 by Kara et al. (2019).

Table 2.9 Data used from the key registries (Kara et al., 2019)

BRK	**BAG**	**BGT**	**BRP**
Parcel number 2D geometry (polygon) Size of land plot Municipality of property Ownership (RRR) Selling price (transaction price) Selling date (transaction date)	*Building* Date of construction Size of building Status (finished, demolished, under-construction) 2D geometry (polygon) *Occupancy units* Address Geometry (point) Size of occupancy unit Date of construction Status Use type (residential, commercial, recreational)	Date of construction Size of building (surface area)	Taxpayer

Table 2.10 Data used/collected by municipalities (Kara et al., 2019)

Primary object characteristics	Secondary object characteristics	Market data
Type of building (detached houses, semi-detached houses, apartments, single family dwelling, multi family dwelling) Type of annex (shed, garage, warehouse) Date of construction Date of construction of annexes Number of annex Size of building Size of annex Size of different part of buildings Special circumstances (e.g. renovated in 1985)	Maintenance condition (interior and exterior of the building) Quality of property (construction material quality, interior quality) Neighborhood Infrastructure Potential nuisances (surroundings, view)	Rent prices Asking price Duration on market

The municipal valuation process uses different methods, using computerised valuation models for large-scale analysis. The approaches of the valuation models can be split up in three ways: sales comparisons, income, and cost approach. Non-residential properties can be assessed using all three of the previous methods. The sales comparison is always used for residential properties. Exceptions are for the non-commercial and non-residential properties that use the depreciated replacement costs. Lastly, agriculture real estate uses the sale comparison based on a national valuation model of all agricultural real estate (Kara et al., 2019).

2.3.2. Valuation of parcel size

Parcel size, as earlier mentioned, is a part of the valuation process of parcels (Kara et al., 2019). This is important in the context of differences in area, in which differences over the set tolerance can lead to increased tax paid or reduced property value (Hagemans et al., 2020). It is seen as one of the primary object characteristics for calculating the WOZ value (Kathmann & Kuijper, 2018).

The value of the parcel size is calculated using the registered parcel size stored in the BRK (Kara et al., 2019). However, the parcel value calculation differs due to different approaches by municipalities in calculating the value of parcels. For example, the taxation collaboration of the East-Brabant in cooperation with the company Ortax specified that the parcel value is based on a price change index and the current ground prices for the area and market segment (Belastingsamenwerking Oost-Brabant, 2021).

Ortax also specifies including an Afnemende Meetwaarde (decreasing added value) to the calculation of the WOZ value. Each additional square meter has less impact on the total valuation of parcels (Belastingsamenwerking Oost-Brabant, 2021). This is also seen in a report by the brokerage institute Morel. Morel specifies a decrease in the added value the larger a parcel gets. They also specify the ground price, valuation time, location, and square metres of land area (Morel Makelaars Instituut, 2015). The report of Oosterveld (2006) shows a similar pattern. The additional value of land increases until the total area reaches a certain threshold, after which it becomes relatively less responsive to further increases in size. In other words, the relationship between land area and value becomes inelastic beyond a certain area.

It is also important to note that multiple cadastral parcels can have multiple valuation units containing different WOZ values, which is possible for parcels of multiple rented apartments. It is also possible to have one general valuation unit with one WOZ value for multiple parcels because the parcels close to each other are merged into one valuation object. Valuation objects are also seen in the Netherlands as WOZ objects (Kara et al., 2022).

Lastly, according to Benduch (2016), accuracy connotation is needed for the parcel size. Benduch mentions that the valuation of parcels uses the registered parcel size without considering the potential error of the value. This is especially important in areas with high land value, meaning an extra accuracy attribute could help with correct valuation. However, Oosterveld (2006) mentions no large difference in ground price for parcels larger than 10.000m^2.

2.4. The willingness of stakeholders

The willingness of the stakeholders to accept cadastral area changes is something on which little research has been carried out. However, there has been research into land redistribution and consolidation efforts. Zhang et al. (2018) describe the effect of land consolidation on the willingness of stakeholders. While Lisec et al. (2014) describe, the perception and satisfaction landowners have with land consolidation. Lastly, the article by Yilmaz, Çağdaş and Demir (2015) discusses an evaluation framework for land readjustment practices.

Zhang et al. (Zhang et al., 2018) describe the effect of land reallocation in the Pengze valley in China. They notice this in heterogeneous areas with a combination of bigger and smaller farmers. Smaller farmers are more averse to changes in their plot size than larger farmers. While the more prominent farmers can benefit from land consolidation, they are relatively less affected by changes in their plot size and their benefits of scale. It is concluded that smaller households should be prioritized in land change policies to lessen the effects of land reallocation. Furthermore, the approach to reallocating land should be suited to the structure of the stakeholders.

Another essential step in successful land consolidation is using good practices and making the process visible to the stakeholders. This means that the active participation of landowners within a project will improve the final result and the process. The participation needs to be well-intentioned and cooperative to smooth the process. Good practices and participation are essential in cases of earlier experiences with land consolidation and cases of emotional attachment to the land (Lisec et al., 2014).

Yilmaz et al. (2015) specify a list of good practices for land readjustment based on land readjustment studies. They split the framework up into the following aspects: Land policy aspects, legal aspects, financial aspects, social aspects, project management, technical principle, capacity building, research and development, technology, data quality and performance assessment. Not all these aspects are relevant in the case of boundary and parcel size adjustments, but a few might still be applicable.

A few of the practices are listed below (Yilmaz et al., 2015):

- A land policy should exist.
- Land readjustment should be implemented systematically.
- The distribution base should only be chosen as the land area in homogeneous areas. For the other areas, the land value should be used.
- Land readjustment should be a flexible procedure for implementing various financial models in different urban areas.
- Uniformity in land readjustment, integration with the related laws and the relationship between Land readjustment and the other land acquisition tools should be ensured.
- Standards should be ensured for all Land readjustment activities and procedures such as planning, subdivision, and valuation.
- In the Land readjustment process, transparency should be obtained.
- Land readjustment should provide equity and equality among landowners in estimating and sharing project costs and profits.
- Landowners' understanding and confidence should be promoted.
- Either land or value base, the allocation criteria should be well-modelled.

2.5. Visualizing differences in area

Visualization of the distribution of errors is essential in finding out which areas will be most affected by the new Cadastral Map. Furthermore, it could be applied to verify current data (Hanus et al., 2018). This means that the data should be correctly visualized to show which areas are affected and the type or shape of these parcels (Kwinta & Gniadek, 2017).

Visualization of parcels also needs to be based on correct topography, which is important in the case of a modern cadastre because they have high-quality requirements (Hanus et al., 2020). The differences in area does not specify the parcel's quality directly but only give an identification of the quality (Hagemans et al., 2021), which means that colours need to be used which do not give an inherent quality meaning and need to be usable with the ordinal classes set in the BEK's norm. Furthermore, data should be visible on a larger scale for all the parcels (Kraak & Ormeling, 2020). Colour ranges in choropleth maps also need to consider a light-to-dark progression. Furthermore, colours need to consider the number of steps easily visible, colour blindness, print friendliness and needed contrast (Brewer, 1994).

According to Wang et al. (2010), visualizing spatial data quality requires definition and representation, such as quality components, database design, graphic methods selection and implementation, dynamic tracking and describing error propagation. Regarding an area attribute, relevant data quality components would be accuracy and positional accuracy in the case of boundary point quality. The components can be used on two hierarchical levels: global and individual. At the same time, the local hierarchical level is only possible for positional accuracy. Furthermore, all measurement scales are possible for visualization.

The quality scale proposed by the Kadaster (Hagemans et al., 2020) can be regarded as an ordinal scale, while the BEK's norm can be viewed as ratio data. Different visualizations are suitable for representing ordinal and ratio data. For ordinal data, visualizations such as position, size, grey values, and grain/texture are commonly used (Kraak & Ormeling, 2020; Wang & Wang, 2010). Wang et al. (2010) suggest that continuous data, which require both attribute and positional accuracy, can be effectively represented using value and colour saturation. When dealing with categorical data, positional accuracy can be enhanced through the use of texture and values, while attribute accuracy can be improved through colour mixing. Lastly, texture/value can be employed for discrete data types to enhance positional accuracy, and value and colour saturation can be utilized to improve attribute accuracy.

2.5.1. Cluster visualization

Another critical step in this research is finding which areas are more affected than others by finding outlier areas. This is because visualization of the outliers can help determine which area is the most and least affected (Hanus et al., 2018). However, it requires information about clustering and determining if a spatial correlation exists between the areas with a negative and positive area. This means that spatial statistics should be applied to the model, for which a spatial auto-correlation analysis and spatial regression are suitable (Anselin et al., 2006).

The process of spatial autocorrelation can be used to visualize the local and global Moran's I statistics. The global Moran's I is displayed using a Moran scatterplot, while the local Moran's I is visualized as the significance and a cluster map. A connectivity diagram can be used to filter out parcels which are locations without neighbours. The spatial clusters can be displayed on the map, displaying clusters with different relations. The relations of the clusters can, for example, be outliers or the relation of both high values surrounded by high values (Anselin et al., 2006).

2.6. Conceptual model

The described theory in the theoretical framework is used in conjunction with the main research question to create a conceptual model. The conceptual model is based on the model of the KKN as described by Hagemans et al. (2021). The model is further enhanced by variables which can impact the implementation. The variables are sourced from the theoretical framework. The conceptual model is displayed in Figure 2.6.

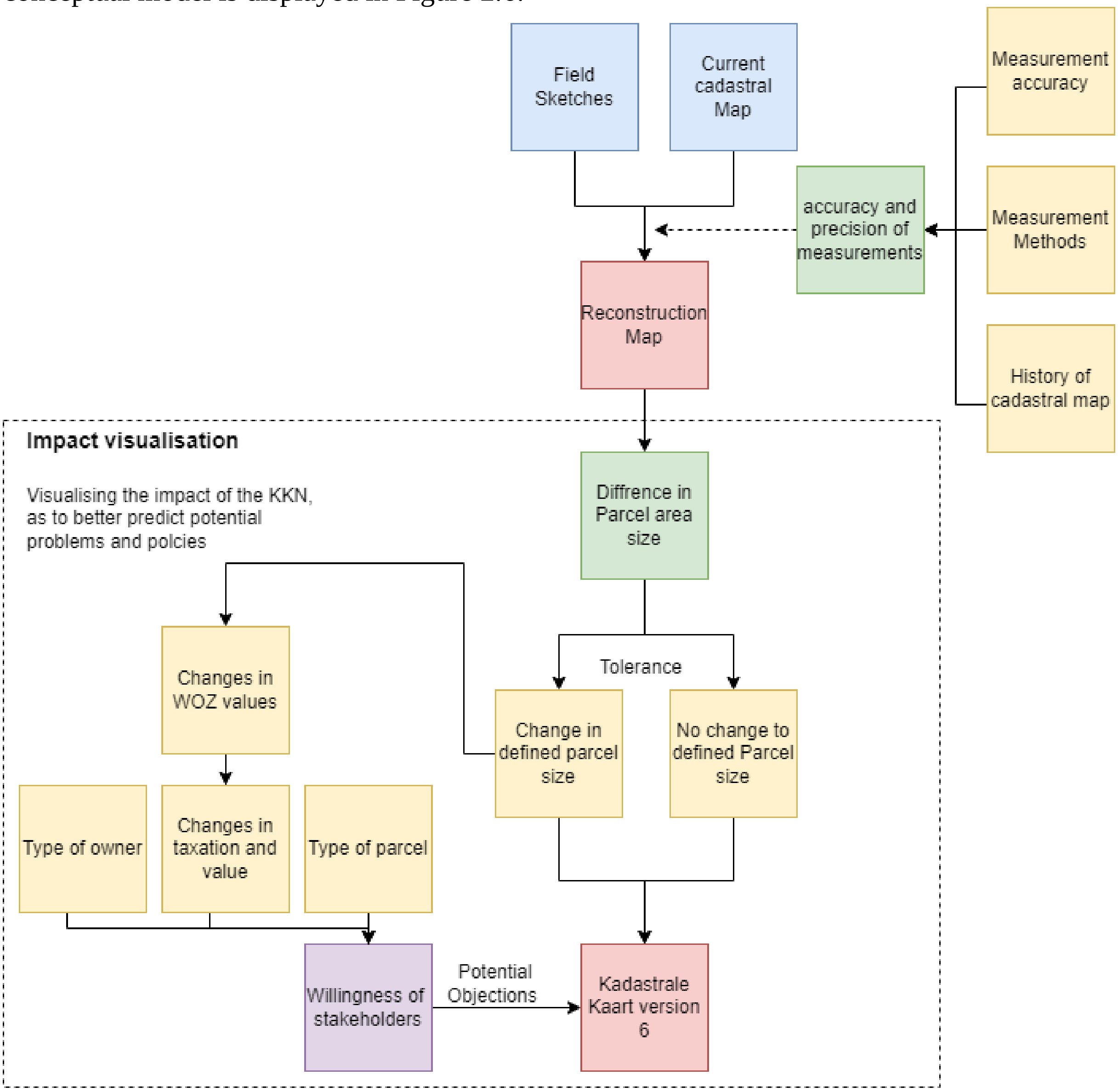


Figure 2.6 Conceptual model of the impact of program KKN

3. Methodology

This chapter will review the methodology to answer the main and sub-questions by showing the tools, methods and data used in this research. The chapter contains the following sub-sections: research area, data requirements, programs, and methods.

3.1. Research area

The current research will be applied to the whole of the Netherlands, allowing for a comprehensive analysis of parcels in the Netherlands. This is made possible by applying calculations using PostGIS inside a PostgreSQL database and data from the Kadaster. However, some calculations, such as finding specific parcel characteristics and clusters, are tested on a smaller scale or be aggregated.

Changing scales by zooming in and out and the use of aggregation is necessary to identify details and visualise smaller parcels. Large-scale visualization only allows identifying patterns of large parcels, which means that the smaller parcels are not as discernable. Discernability makes therefore splitting the Cadastral Map into smaller entities necessary. Furthermore, the pilot data only applies to eighteen parcels in the Netherlands and requires visualization on a lower scale.

As such, the Cadastral Map is split into three different subdivisions based on categories in the BRK and the internal use by the Kadaster. These subdivisions are cadastral municipalities and cadastral sections. This research also includes a visualization of the KKN pilot area inside the cadastral section of Nieuwkoop. The subdivisions based on sections and municipalities are shown in Figures 3.1 and 3.2.

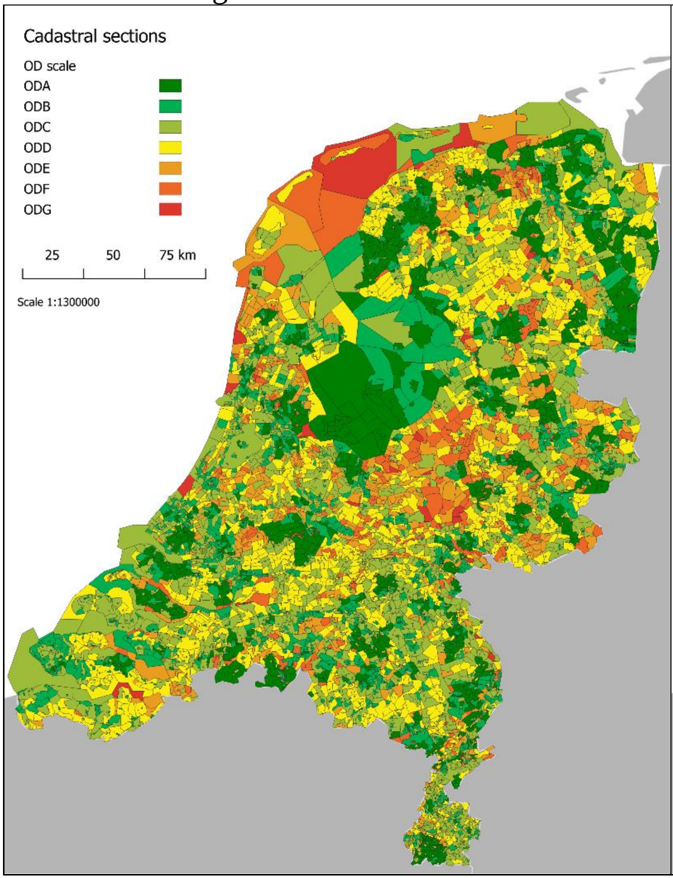


Figure 3.1 Cadastral sections in the Netherlands

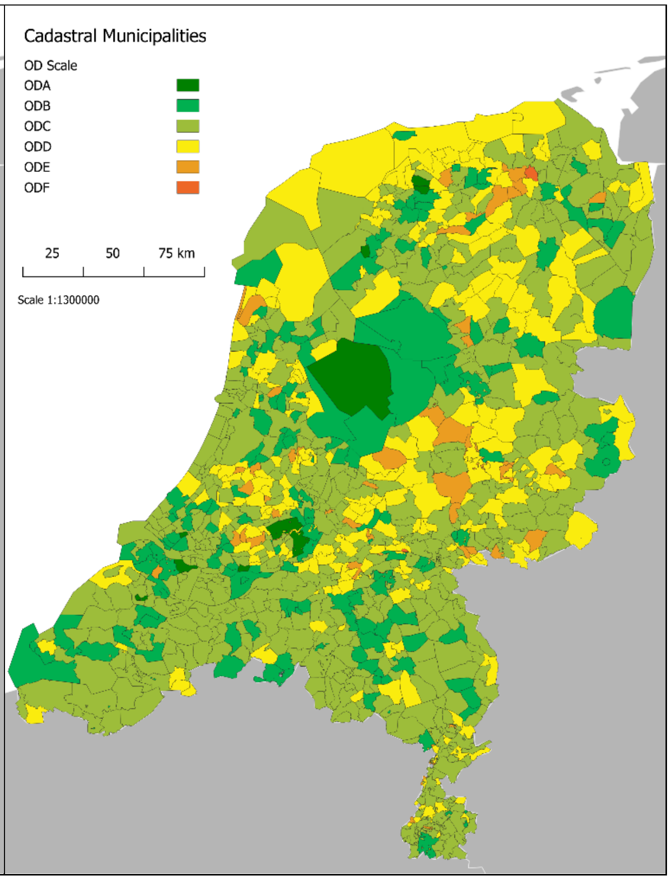


Figure 3.2 Cadastral municipalities

One cadastral province map and one cadastral municipality map are also shown to give an in-depth overview of smaller areas and show local visualization of the impact. One is the cadastral province map of Utrecht and the cadastral municipality map of Nieuwkoop. The province of Utrecht has the least number of parcels compared to other Dutch provinces and has a diverse landscape, making it performance-wise easier and diverse enough to analyze. The municipality of Nieuwkoop contains the KKN pilot data and can be used to analyze the potential impact of the KKN.

The KKN pilot data is limited to around 196 field sketches located near Slikkendam. This is also displayed in the article by van den Heuvel et al. (2021). However, the pilot data available for this research is limited to 18 complete parcels in the hamlet of Slikkendam. These 18 parcels were the only complete set directly available from the field test. The area of Slikkendam is shown in Figure 3.2.

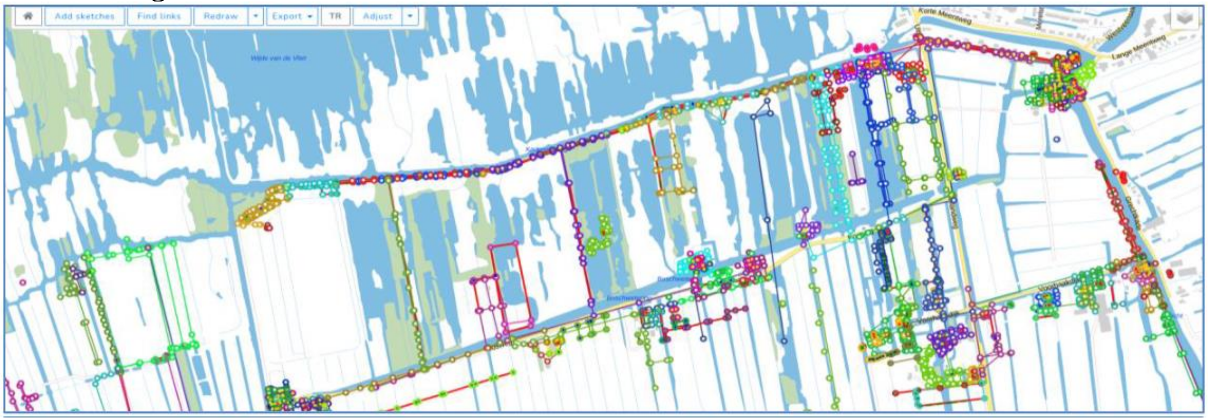


Figure 3.2 Visualization of the network of the KKN pilot, from van den Heuvel et al. (2021).

3.1.1. Pre-processing the data of the map, removing outliers

The next step is ensuring that the data is ready for spatial analysis. This requires that outliers do not significantly influence the data and that no islands exist in the dataset. These outliers and islands can potentially be dataset errors or measurement mistakes. Removing these outliers in the dataset ensures that data are accurate and that they give a correct picture of reality; however, some outliers are still relevant for this research because they may be parcels of old/wrong measurements.

Outliers are selected by selecting parcels outside three times the standard deviation of the mean M-value. These outliers are selected using the program GeoDa, to determine which areas are impacted and where these areas are located. The visualization uses a boxplot and a map containing all the parcels in the Netherlands. It is then possible to highlight the outliers on the map by selecting the upper outliers in the boxplot itself.

Applying a boxplot to the complete dataset shows that the dataset has extreme outliers. The result shows that the dataset has extreme outliers outside three times the Standard deviation (SD = 1.3546). Applying a selection shows that 12682 parcels, with their M-value, can be seen as outliers. A clear pattern is seen for parcels along the border of the Netherlands in the North Sea and in other potential clusters of parcels with a high M-value, such as in areas that contain nature.

The highest outlier is a parcel in the province of Groningen, with an M-value of 2528,138. Inspecting the parcels shows a large discrepancy in the registered- and calculated surface area of parcels. The calculated surface area of the parcel is around 10% of the official parcel size. A reason for this difference could be a mistake in the input of the official measurements, where a dot between 8 and 4 is missing. The boxplot and parcels are shown in Figures 3.3a and 3.3b.

More mistakes are identified and fixed in the final dataset by moving the decimal for extreme outliers, where a decimal input error can explain the area difference. Taking into account rounding, the decimal error can be found in cases of a 10* or 100* factor difference between the registered and calculated surface area. Fixing visible errors is only done for the 100 top outliers. The fixed parcels are displayed in the annex 1 document.

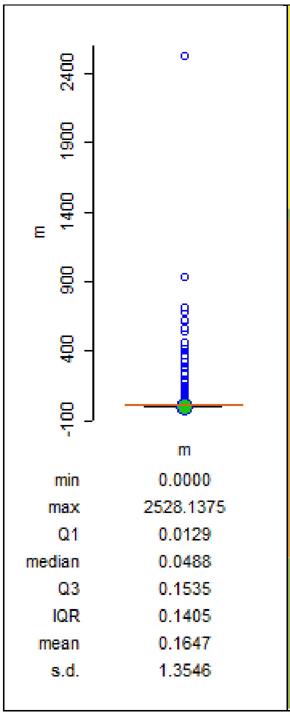


Figure 3.3a A Boxplots, where m stands for the M-value.

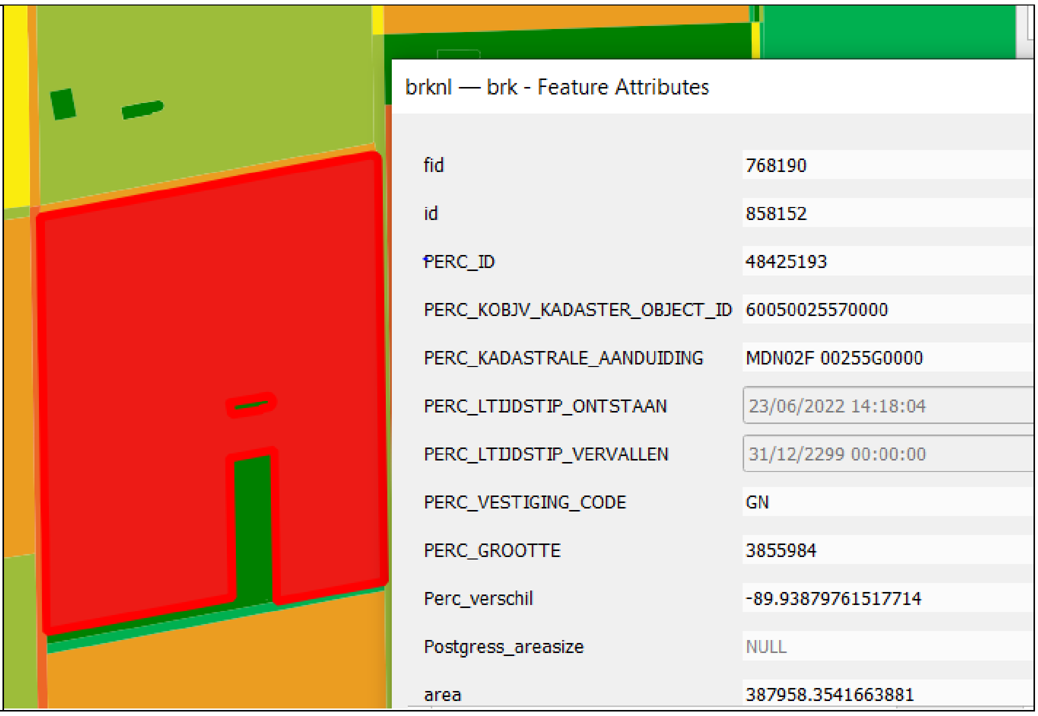


Figure 3.3b Shows the parcel which is an outlier in the BRK dataset, with a factor 10 difference in area.*

When looking at continuous areas of outliers, it is possible to identify the North Sea coast of the Netherlands directly. This area is fully contained inside a specific cadastral municipality of Noordzee. The Noordzee municipality has a general M = 50 value, vastly exceeding the three times standard deviation (M = 1.3546). The municipality boundary is around the 12-sea mile legal sea border (Noordzeeloket, 2023). Mistakes in measurements or faults in the conversion of the data might explain this discrepancy in the sea border because the North Sea boundaries of the parcels follow the coast of the Netherlands.

As such, the municipality of Noordzee is removed from the dataset because it is a significant outlier irrelevant to the impact measurement. Because firstly, the municipality is located on the border of the Netherlands, and the parcels do not have the neighbouring land parcel. Secondly, the municipality might significantly influence the results and the area of the parcels because of its mean M value of 55.06 and area differential of around 2.445%.

Other municipalities, sections and parcels are not removed from the dataset because they might cause islands in the dataset. Furthermore, they are relevant for the spatial impact because they may be old measurements and might influence other parcels next to it.

3.1.2. Connectivity of the dataset and weights

The next step is creating a weight file to test the dataset's connectivity and allow spatial analysis. The weight file created for this research uses standard weights with a queen's contiguity file. Queen's contingency ensures that boundaries only connected on points are included (Anselin, 2020a). To ensure that all neighbouring parcels are included in the dataset, the assumption is that the parcels' area only influences the parcel's direct neighbour. When the size of the parcel changes, the other parcels could change with them. Furthermore, distance weighting is unnecessary in this case because parcels can be of different sizes. This research does not need to show if a parcel is within a certain threshold distance.

The weight file shows that islands can be found inside the dataset, and the parcels have a median of 5 parcels and a mean of 5.81. The dataset only contains one island. This island is in Baarle-Nassau and does not border any Dutch parcels. This island is removed in the final selection of the Cadastral Map.

3.1.3. Final selection

The final selection is a map containing the parcels in the Netherlands by removing the outliers in the data, which have an area difference of a factor of 10* and 100*, parcels without connectivity to other parcels. This is done by removing the parcels containing the keyword NZE (Noordzee) and removing/editing specific parcels. The final selection is shown in Figure 3.4.

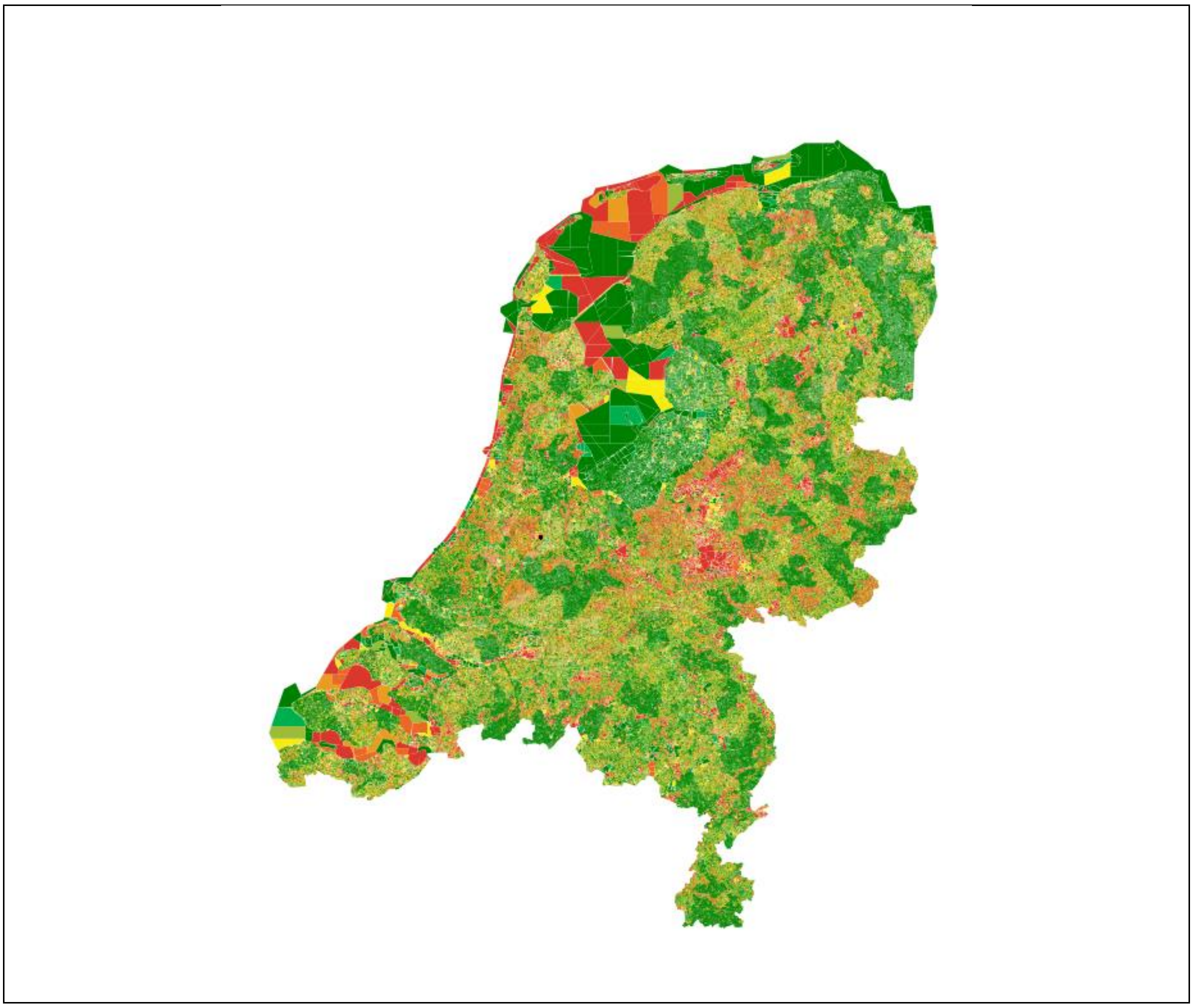


Figure 3.4 Included parcels in the dataset.

3.1.4. Linking KKN pilot data to the current BRK

The KKN pilot data are of limited size because there are only 18 parcels available to compare with the actual size of the parcels. Furthermore, the pilot data only contains the new boundaries of the parcels and the transformation. In comparison, the pilot data should be transformed into polygons and linked to the BRK.

As such, boundaries are tested for topological errors and made sure that the segments snap to each other. Then the boundaries not part of a polygon are pruned from the dataset, ensuring that only the polygon boundaries remain. The boundaries are then polygonised and linked using the ST_WITHIN function to the BRK dataset, which can then be used to analyse the impact of the KKN. The resulting polygons and the original boundaries are shown in Figure 3.5.

The resulting polygons, however, differ from the BRK dataset, in which two parcels have been merged. According to the BRK variable of PERC_LTIJDSTIP_ONTSTAAN on 10-12-2010, this change affected four parcels. As such, the data has to be changed to make it operable for analysis.

Only one change is necessary to make it comparable to the old situation. This is done by merging two old parcels in KKN. Outer parcel boundaries did not change by merging the parcels. This is visible when looking at the shift of the boundary vertices compared to the current Cadastral Map; the shift shows the precise location of the original outer vertices of both parcels compared to the new situation of the KKN pilot, see Figure 3.5. As such, the calculation of the m value uses the area of the sum of both parcels' official areas (111 m^2+ 129 m^2= 240 m^2).

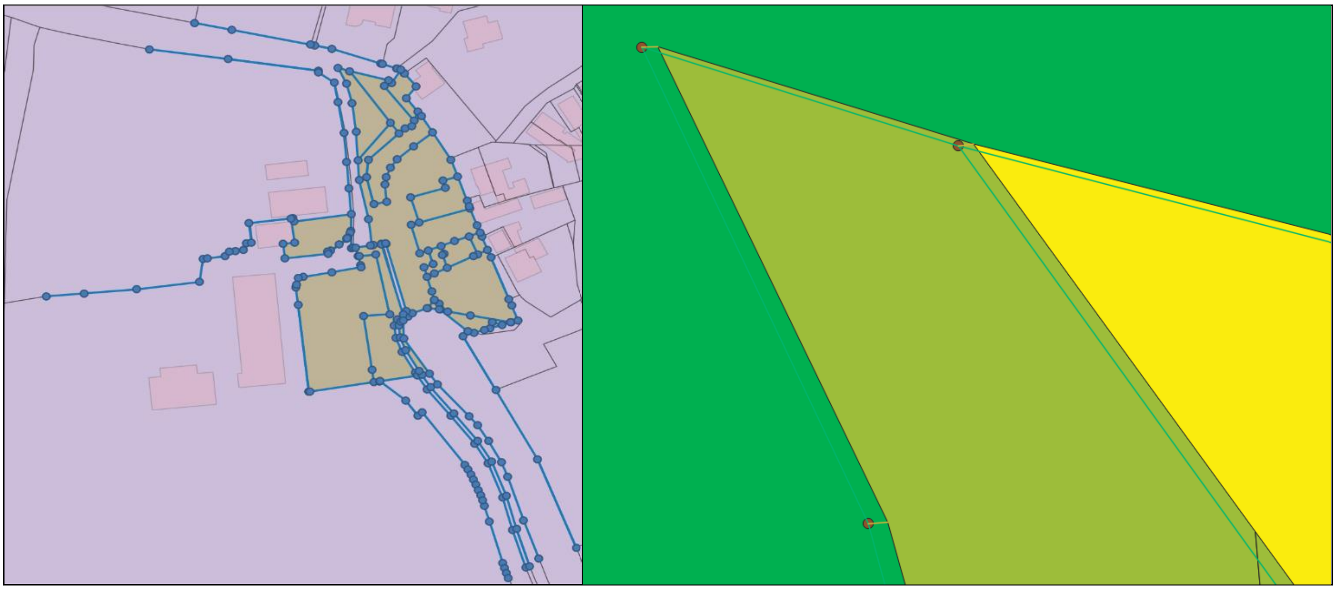


Figure 3.5 Boundaries of the KKN pilot with the resulting polygons and the shift of the original polygon need to be merged.

3.2. Data Requirements and Programs

This research will use a variety of different tools and data. The data is primarily sourced from the Kadaster, in which the current BRK is the primary dataset. From the BRK, various calculations can be made about the area. Rural and built-up areas are selected using data from the TOP10Nl. The TOP10NL contains the contours of built-up areas and is also for this purpose used by the Kadaster (Hagemans et al., 2020).

The pilot data and parcel ownership are sourced directly from the Kadaster. These datasets are, however, not public. Furthermore, the KKN pilot data is stored as a GeoPackage file containing the new/old boundaries and the shifts of the parcel nodes. The Basisregistratie Adressen en Gebouwen (BAG) is sourced from PDOK to select parcels containing a building or a living object in the Netherlands. Natura 2000 is also sourced from PDOK and allows identifying parcels in nature areas. The used data is also shown in Table 3.1.

Table 3.1 Datasets used in this research.

Name	Format	Source	Comment
KKN pilot data	.gkpg	Kadaster	
Basisregistratie Kadaster (BRK)	.gkpg	Kadaster	Contains Parcels and registered area
TOP10NL	.gpkg	cbs.nl	For selecting rural or build-up
Parcel Ownership	.shp	Kadaster	Data specifying public or private ownership and municipality
BAG	. gkpg	PDOK	Basic registery for selecting Verblijfsobjecten
Natura 2000	.gkpg	PDOK	Nature areas with a 2000 classification

The data is analyzed using four programs:

- The spatial statistical analysis is done using Geoda, which allows for a direct link to the PostgreSQL server.
- The visualization is done in QGIS. QGIS has been chosen over ArcGIS because QGIS has better compatibility and interoperability with PostGIS. Furthermore, QGIS is open-source, and it allows anyone to repeat and visualize this research.
- PostGIS is used for efficient and performant storage of cadastral data within a PostgreSQL server. PostGIS also allows geographic data to be processed using SQL statements. PostGIS allows easier integration with GeoServer when designing a web-based visualization application.
- Lastly, Excel is used for editing and making minor changes and data conversions of small datasets. The programs applied are listed in Table 3.2.

Table 3.2 Programs used in this research.

Name	Comment
GeoDa	Spatial statistical analysis
QGIS	QGIS used for the spatial analysis
PostGIS server	Storage and processing of spatial data
Excel	Processing excel data

3.3. Preparation of the primary dataset

The data is prepared by including the derived surface area and the perimeter of parcels. Preparation is necessary because the BRK only contains the registered area of parcels but not the calculated surface area and perimeter. This means that the area needs to be calculated using the ST_AREA functions of PostGIS. The perimeter length is calculated by the PostGIS function ST_Perimeter. The resulting values are in square meters and meters, respectively. The used functions and processes are also shown in Figure 3.6 and Figure 3.7.

The dataset sourced from the Kadaster is to be appended with additional data from multiple sources. This data, however, cannot always be linked to the current BRK because the used BRK dataset does not contain the necessary attribute to link to other datasets like the BAG. In the case of the BAG, the Kadaster also applies different systems for linking the datasets by comparing the geometry of Verblijfsobjecten with the Cadastral Map (Gemeente Amsterdam, 2023), which does not require the data to be joinable in an attribute. Some attributes are added to the database by appending the table when it covers more than 50% of a parcel.

```
-- natura 2000
UPDATE "Percelen"."BRK" as brk
SET natura2000 = (CASE WHEN (st_area(st_intersection(brk."geom", ntr2000."geom"))/st_area(brk.geom) > 0.5) = 'TRUE' THEN 1
                 else 0
                 END)
FROM "Percelen"."natura2000" as ntr2000
WHERE st_intersects(brk."geom", ntr2000."geom")
;
```

Figure 3.6 Example of Postgres functions to set a variable based on the area cover.

The parcel ownership data is joined on the "PERC_KADASTRALE_AANDUIDING" in Postgres. The join, however, requires a transformation of the format of the parcel identifier. First, the white space and extra zeros in both variables should be removed. The variables are also restricted to the section identifier and the parcel number only; the functions are shown in Figure 3.8.

```
ALTER TABLE "Percelen"."BRK" ADD COLUMN section text;
UPDATE "Percelen"."BRK" as brk
SET section = left(brk."PERC_KADASTRALE_AANDUIDING",6);

ALTER TABLE "Percelen"."BRK" ADD COLUMN perceelnum text;
UPDATE "Percelen"."BRK" as brk
SET perceelnum = LTRIM(substring(brk."PERC_KADASTRALE_AANDUIDING",8,5),'0');

ALTER TABLE "Percelen"."BRK" ADD COLUMN perceel text;
UPDATE "Percelen"."BRK" as brk
SET perceel = (brk."section") || (brk."perceelnum");

ALTER TABLE "Percelen"."VERGUNNINGENKAART" ADD COLUMN perceelnospace text;
UPDATE "Percelen"."VERGUNNINGENKAART" as vrk
SET perceelnospace = regexp_replace(vrk."perceel", ' ', '', 'g');
```

Figure 3.7 PostgreSQL functions used to join on the parcel identifier.

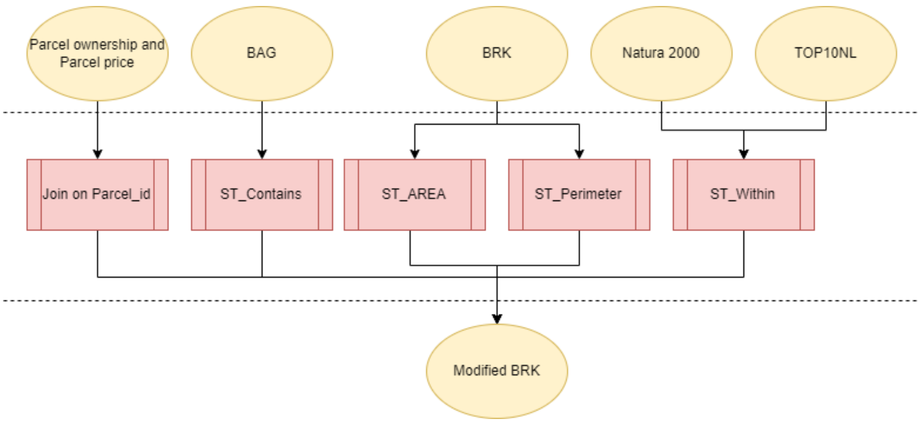


Figure 3.8 Process of updating the BRK dataset.

3.4. Calculating the area diffrence

The difference in area is calculated using data from the registered and calculated surface area of the parcels in the Netherlands. It is possible to calculate these area differences by using a simple percentage difference formula. However, this is not suitable for identifying differences in the quality of parcels because the difference would not consider a parcel's length-width ratio. The area difference in a parcel with a relatively longer perimeter impacts the boundary relatively less than in a case of a perfect square perimeter because the boundary is more extended for the same area.

The earlier described formula of BEK's based on HTW96 calculates the area difference between the parcels, and this result is then used to calculate the Bek's value. The Bek's value is then used to classify along the seven earlier mentioned classes of the oppervlakte delta table. See Figure 3.9 and Figure 3.10.

The calculations are done using the following formulas based on the formulas specified by Hagemans et al. (2020). In the formula, the following variables are used:

Input variables:
OPP → Calculated surface area in square meters.
GRT → Registered area in square meters
OMT → Perimeter of the parcels in meters

Resulting variables:
LBV → Length-width ratio
DLT → Surface delta
M → Normalized delta (M)

These are used in the following formulas:

$$LBV = \frac{(OMT)^2}{4*OPP} - 2$$

$$DLT = OPP - GRT$$

$$M = DLT/\sqrt{(LBV * OPP)}$$

The formulas are described and updated using the following SQL statements.

```
UPDATE "Percelen"."BRK" SET area = ST_AREA(geom,28992);
UPDATE "Percelen"."BRK" SET omt = ST_Perimeter(geom,28992);
UPDATE "Percelen"."BRK" SET lbv = (omt)^2/(4* area) - 2;
UPDATE "Percelen"."BRK" SET dlt = "area" - "PERC_GROOTTE";
UPDATE "Percelen"."BRK" SET dltabs = @dlt;
UPDATE "Percelen"."BRK" SET M = @dlt / |/(LBV * area);
UPDATE "Percelen"."BRK" SET "Perc_verschil"= (area - "PERC_GROOTTE")/"PERC_GROOTTE" * 100;
```

Figure 3.9 PostgreSQL statements for calculation of area

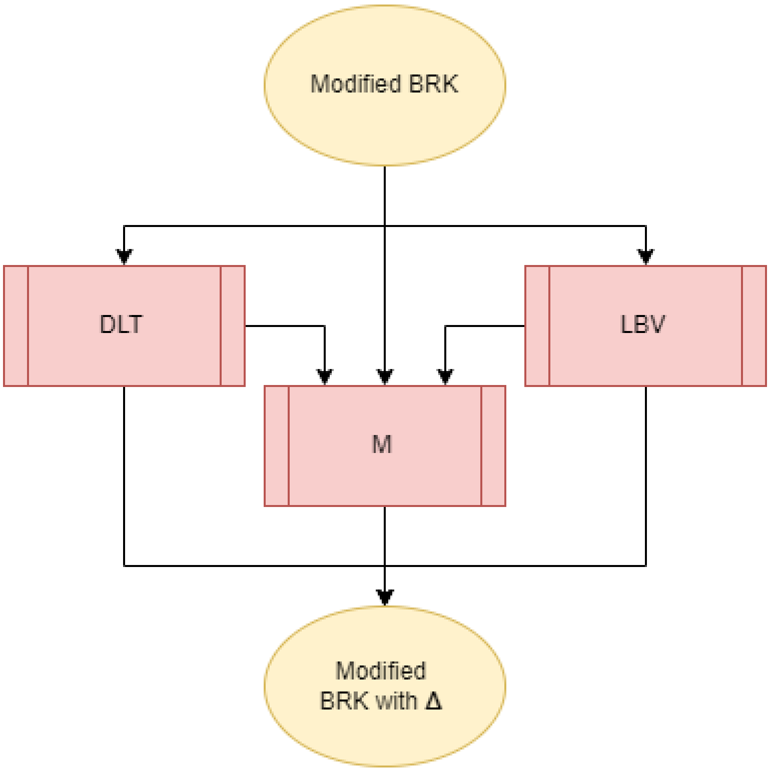


Figure 3.10 Calculating the area difference.

The final result of the M-value is used to determine the parcel's classification based on the copperplate delta table; this is shown in Figure 3.11. The table describes the potential reason for the difference between the registered and calculated surface area. Furthermore, the Length-width ratio and Surface delta can be used to explain parcel-specific features.

```sql
UPDATE "Percelen"."BRK" SET od = CASE
WHEN m <= 0.0566 THEN 1
WHEN m BETWEEN 0.0566 AND 0.1077 THEN 2
WHEN m BETWEEN 0.1077 AND 0.2236 THEN 3
WHEN m BETWEEN 0.2236 AND 0.4213 THEN 4
WHEN m BETWEEN 0.4213 AND 0.8246 THEN 5
WHEN m BETWEEN 0.8246 AND 1.612 THEN 6
WHEN m > 1.612 THEN 7
END ;
```

Figure 3.11 Giving parcels an OD-value based on the M value.

3.5. Calculating the change in the value of parcels

The change in value will be based on the ground price of parcels. The calculation will use one-time ground-price value linked to the parcels, combined with the information from the Waarderingskamer and the literature. The land's value will be based on the assumption that the value of extra land will decrease the more available land there is.

The formula itself will be created from the last sale data of the Kadaster, which is included in the attribute table of the BRK. The data will be combined with data from the BAG to select new parcels in the Netherlands which have the status 'Verblijfsobject' formed. The status 'Verblijfsobject formed indicates that it is a new parcel and that it is possible to assume the parcel price is purely the ground price. This can be repeated for all parcels with a 'Verblijfsobject' formed. The resulting data can then be used to derive the ground prices of each m^2 for each parcel. The ground price per parcel can then be used to calculate a price coefficient to predict the impact of the surface area of a parcel on the ground value.

The land value price coefficient is calculated using two functions within Postgres, regr_slope (Y, X) and regr_intercept (Y, X). These two values allow for finding the intercept and slope of the relation between area and land value; if needed, the formula can be made exponential using the log function. This is done with a selection of new parcels with no Verblijfssobject inside. The resulting best-fit line will then be used to calculate the change in land value. This is also displayed in Figure 3.12.

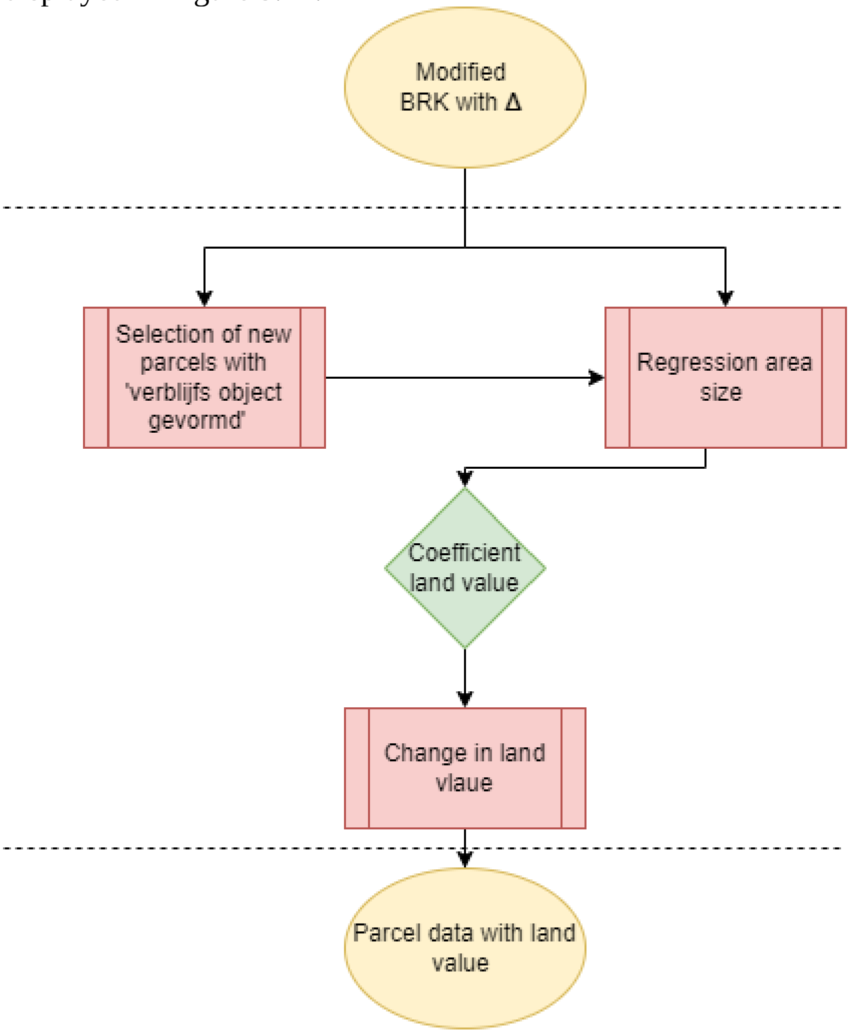


Figure 3.12 Calculating the WOZ value.

3.1.Splitting parcels into subdivisions

The complete BRK dataset is unsuitable for all the analyses and visualizations in this research. Focus on a smaller scale allows better visualization of smaller parcels while aggregating allows better identification of impacted areas. As such, the areas are split and aggregated on the attribute PERC_KOBJV_KADASTER_OBJECT_ID; the areas are cadastral provinces, municipalities, and sections. A general overview is given in diagram 3.13.

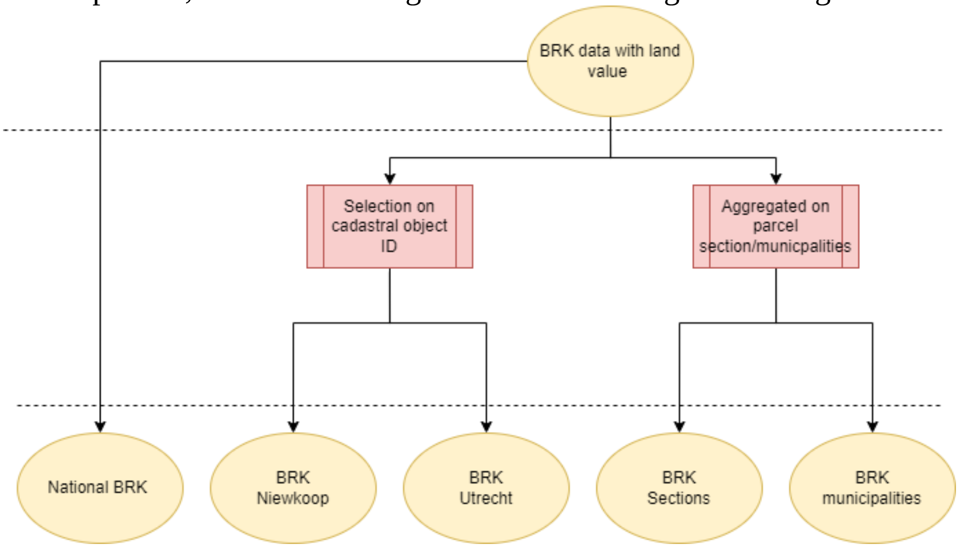


Figure 3.13 Splitting and merging of parcels

The aggregation adds a few extra variables to the dataset, the mean M-value and area difference calculated for each section/municipality. Furthermore, the time of parcel registration, based on the mean epoch time, is added to the dataset. Lastly, the total amount of each parcel is given for each of the sections/municipalities. The selection of the new parcels does not add any new information to the dataset. An example of the SQL query is shown in Figure 3.14 below.

```sql
Create Table "Percelen".cadastralmunicipalities AS
select
    St_Multi(ST_Union(geom))::Geometry(MultiPolygon,28992) AS geom,
    SUM(dlt) AS dltsum,
    AVG(m) AS mavg,
    SUM(dltabs) AS dltabssum,
    SUM("PERC_GROOTTE") AS areaold,
    LEFT("PERC_KADASTRALE_AANDUIDING",5) AS munid,
    AVG("epochdate") as avgepochdate,
    COUNT("id")as totpercelen
FROM "Percelen"."brkclean"
GROUP BY left("PERC_KADASTRALE_AANDUIDING",5);
```

Figure 3.14 SQL query for aggregating on cadastral municipalities.

3.2.Spatial analysis of parcels and visualization of area differences

The calculated results will be utilized for conducting spatial analysis. Initially, a preliminary visual analysis of the data will be conducted, followed by the spatial analysis using GeoDa. Subsequently, spatial statistics will be performed within the GeoDa software.

The spatial regression will be used to analyze the link between two variables, testing if there is a correlation between variables, such as the owner type and the Normalised delta. Furthermore, a spatial autocorrelation will be used to find clusters of parcels and the homogeneity and heterogeneity of these clusters. The type of parcel will be selected based on internal criteria set by the Kadaster (Hagemans et al., 2020).

The weight file created for this research uses standard weights with a queen's contiguity file. Queen's contingency ensures that boundaries that are only point-connected are included. To ensure that every neighbour of parcels is included in the dataset, the assumption is that the parcels' area only influences the parcel's direct neighbour. When the size of the parcel changes, the other parcels change with them. Furthermore, distance weighting is unnecessary in this case because parcels can be of differing sizes, and this research does not need to show if a parcel fits within a specific distance threshold value

The spatial autocorrelation will use different techniques; the M-value uses the local Moran's I inside Geoda. While Local Moran's I work with ratio/ scale and ordinal values, other extensions are unnecessary (Anselin, 2020b). While for binary variables, the Joint Univariate Local Join Count Statistics is used because this technique works with binary data to find clusters in the dataset.

In order to achieve the optimal cartographic visualization of the effects of the KKN (Kadastrale Kaart Next), a specific set of requirements need to be met. Firstly, the visualization should adhere to the standard topographic rules of map design as outlined by Kraak and Ormeling (2020). This ensures consistency and readability in the representation of spatial information. Additionally, the cartographic visualization should comply with the standards set by the Kadaster, incorporating all the necessary information required for accurate decision-making.

The visualisation mainly uses the data about the M-value to display the changes in area using the colour schema set by Cadastre. Area differences and outliers are on this way easily shown. And sections and municipalities with a more significant difference in area can also be identified this way. The schema below shows the process of this research

The results from this analysis are compared with the KKN pilot data to show the impact and the difference in patterns in the parcel boundaries and parcel area of the pilot and the current Cadastral Map. A general overview of this process is shown in Figure 3.16.

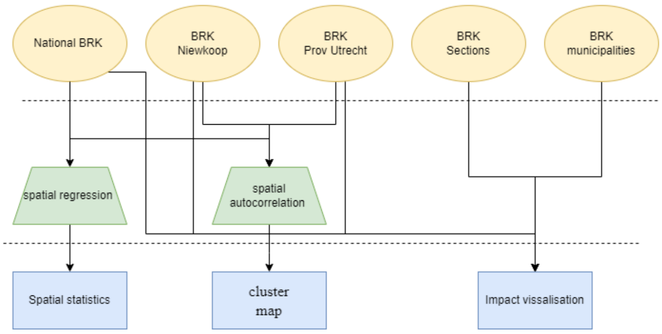


Figure 3.15 The spatial analysis and visualisation

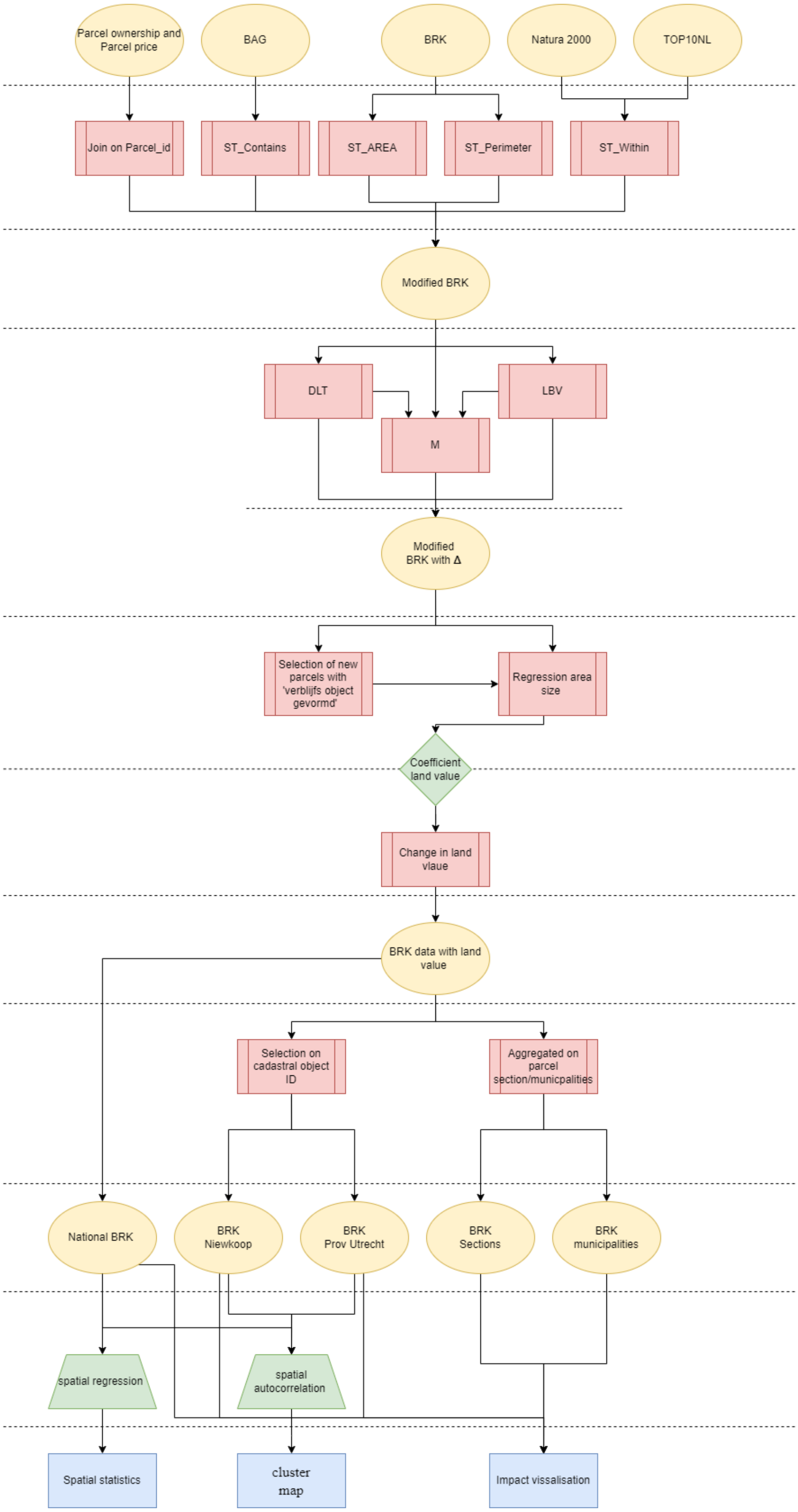


Figure 3.16 Overall scheme of the methodology

4. Results

This chapter will go into the results of this research and will give a current overview of the area differences using the current BRK. This chapter will first focus on exploratory and spatial statistics on a national level. Next, the cadastral province of Utrecht and the municipality of Nieuwkoop are analysed. At last, the KKN field test in Nieuwkoop is analysed and compared to the current Cadastral Map.

4.1. National Overview

Results show that the Netherlands' total area is subdivided into 8212821 parcels. Of those parcels, 6252956 are situated inside built-up areas. 1959865 parcels are situated inside rural areas. Of which 5282502 parcels contain a building, accounting for 63.32% of the total number of parcels. These numbers show that most parcels are inside built-up areas or contain a building; these parcels are also relatively smaller than parcels in rural areas.

An overall analysis of the area shows that the total calculated surface area is 41543365881 m^2. In comparison, the registered area is 41511056366 m^2, which means that the official total registered area is 0.078% smaller than the calculated surface area of parcels in the Netherlands. The result gives an answer to the hypothesis: "*The registered area of the Netherlands is smaller than the actual calculated surface area.*". This leads to the rejection of the null hypothesis (H0), which suggests no significant difference in the total area of parcels. Instead, support the alternative hypothesis (H1) that there is a significant difference between the total area of parcels between the registered and calculated surface areas. An overview is given in Table 4.1.

Measuring the relative difference between the official parcel size and the calculated surface area is done using the BEKS norm. Using GeoDa, an exploratory overview is visualized using a histogram of the total share of unique OD categories. These OD categories are based on the classification table of Bek's norm displayed in Table 2.8. The overview shows that around 53.124% can be categorized within the highest category ODA, which means that most parcels are strongly correlated or are both of high quality. The OD values also show that around 3.546 % are outside the current cadastral norm for rural areas, and 8.619% of parcels are outside the norm for built-up areas in the Netherlands. The overall mean OD value for the categories is 2.105, with a standard division of 1.47. The median OD value indicates that most parcels do not need to change with the implementation of the KKN if the KKN stays more or less equal to the current cadastral map. The results are visualized in Figure 4.1.

Repeating the analysis for the M-value gives a similar result, for which the mean M (M = 0.16, SD =1.35) value fits within the third category of the value table, ODC. The ODC category means that the registered area of parcels does not need to be changed by applying the rules set by the Kadaster. However, this only gives an overview of the Netherlands and omits outliers, spatial patterns, parcel types and location of parcels. Following this, a subdivision on parcel type can be made to identify parcel land types which might have a relatively significant difference in registered and calculated surface area.

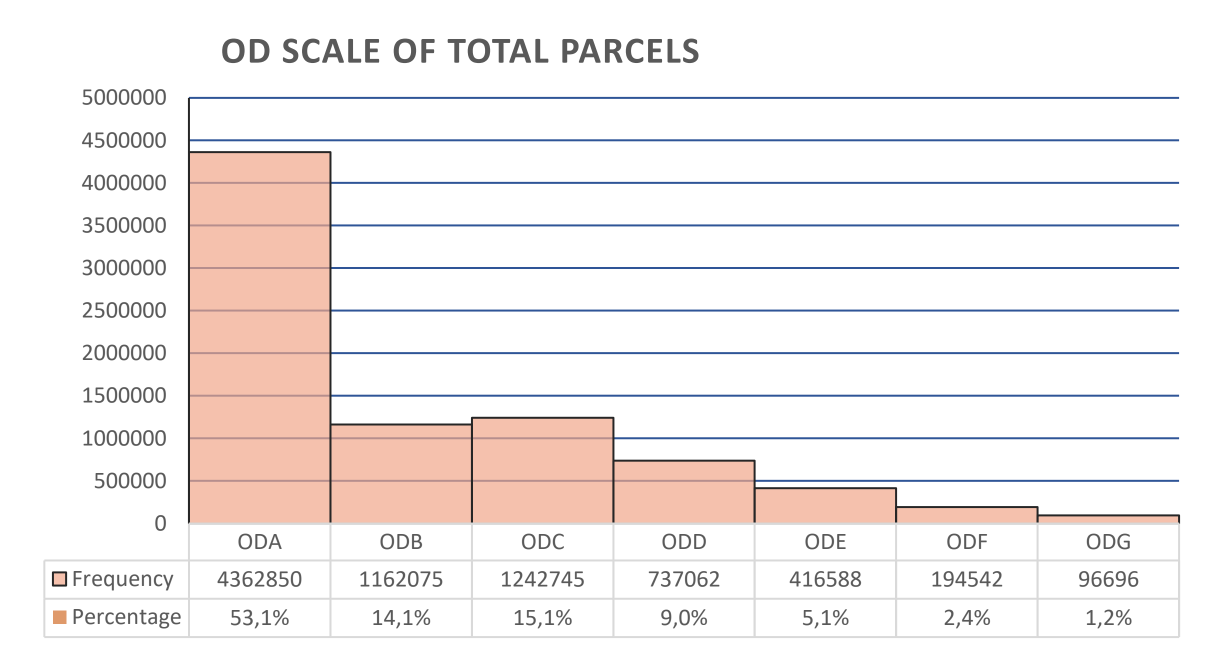


Figure 4.1 Histogram OD values of the Netherlands and the number of parcels in each category

Table 4.1 Total area

Total area	Area size in m^2	Percentage
Sum registered area	41511056366	100 %
Sum calculated surface area	41543365881	100.078 %
The difference in area	32309514,2	0.078 %

Table 4.2 Total amount of parcels

Parcel type	Number of Parcels	Percentage of total
All	8212821	100 %
Built up areas	6252956	76.13 %
Rural areas	1959865	23.86 %
Building	5282502	64.32 %
Nonbuilding	2930319	35.68 %

4.2.Selection of parcel types

This research uses selections to identify the potential impact of the new Cadastral Map on different land-use types. A parcel selection allows comparing different parcel types to the mean and unselected parcels. Furthermore, a selection identifies the impact on a much larger scale. This study uses four potential selection criteria:

1. Built-up and rural areas based on the TOP10-NL,
2. Parcels containing the variable "Verblijfsobject", which includes residential and other parcel uses like; industry, sport and education.
3. Parcels containing the variable "Woonfunctie." are limited to only residential.
4. Parcels containing Natura2000 areas
5. Governmental parcels.

Other selections are also possible using a large variety of sources.

4.2.1. Built-up areas and Verblijfsobject

The first two selections are built-up and "Verblijfsobject." Of which built-up parcels are located more than 50% inside the TOP10-NL built-up contours. The variable 'Verblijfsobjecten' are parcel containing a residential, commercial, or recreational function unit and is sourced from the BAG. The cartographic visualisation would indicate more parcels with the "Verblijfsobject"; however, this is not the case and can be explained by parcels in built-up areas being smaller and, as such less visible. These two selections are shown in Figure 4.2 and Figure 4.3 below.

Figure 4.2 Selected Parcels within built-up areas

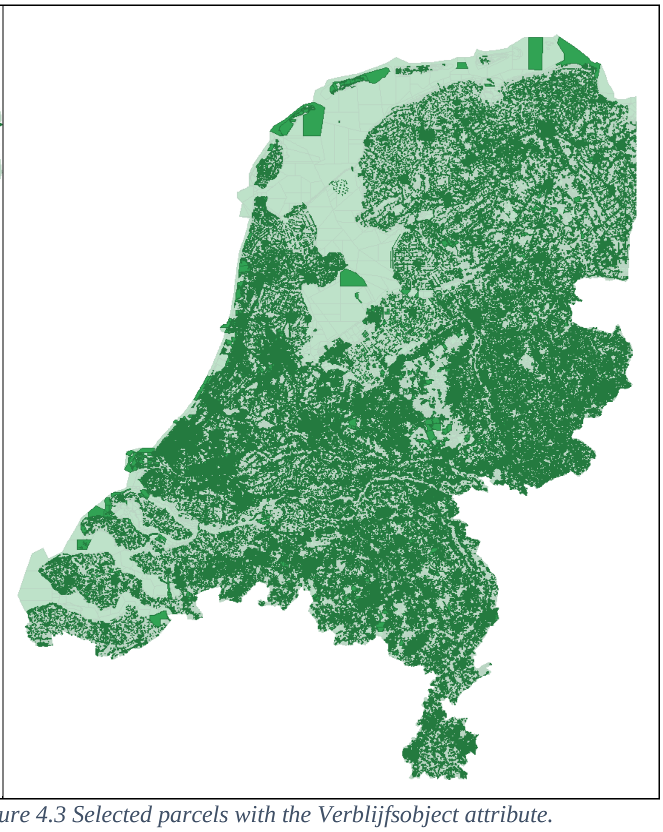


Figure 4.3 Selected parcels with the Verblijfsobject attribute.

Both selections can be used to visualize the general OD values for each municipality. These results show a relatively higher reduction in the frequency of OD values higher than the ODC category, with a significant reduction in the frequency of ODG parcels in comparison to the national data. In the case of parcels with a Verblijfsobject, the ODG values range from 2705995 of all parcels to 20503 for parcels which include a Verblijfsobject, a reduction of around 98.8%. The reduction aligns with the fact that areas within built-up areas historically have a higher quality requirement for maximum area deviation.

Table 4.3: OD distribution of Built-up parcel with their value

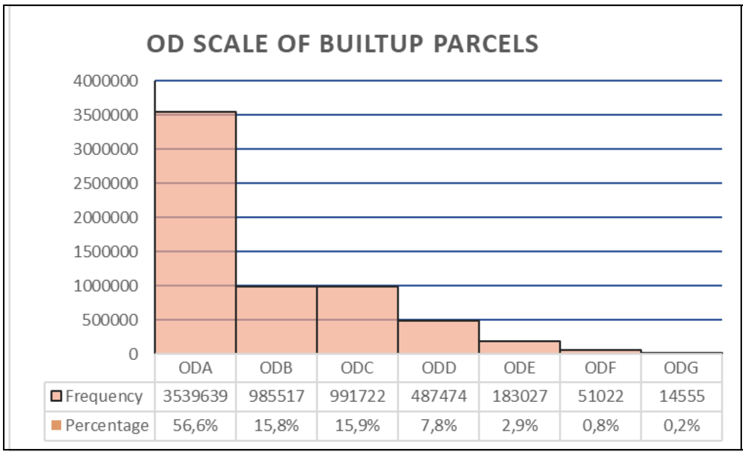
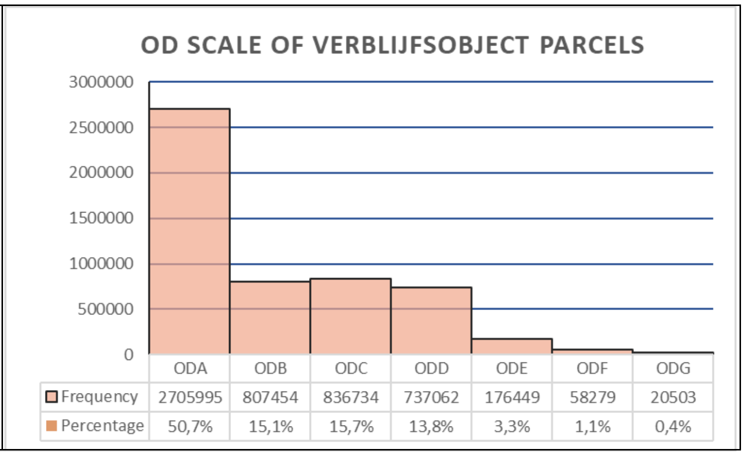


Table 4.4: OD distribution of Verblijfsobject parcels



A similar result can be seen when looking at the mean M-value of parcels inside and outside the two selections. The selected M-values of parcels inside built-up areas (M = 0.10, SD = 0.22) are significantly lower than in rural areas (M = 0.35, SD = 0.85). This means the area difference is significantly higher in rural areas with a large spread. This effect is less pronounced for parcels containing a Verblijfsobject (M = 0.11, SD = 0.26) than parcels that do not contain a Verblijfsobject (M = 0.26, SD = 0.71). This might be explainable by the location of parcels containing a Verblijfsobject. These parcels can be situated outside the built-up areas and contain objects like vacation houses or industrial buildings. The results are shown in Tables 4.4 and 4.5 below.

The selection results can be used to answer the hypothesis; *Rural areas differ more than the built-up areas between the registered and calculated surface area than the built-up areas*. As presented in Table 4.4, the statistical findings indicate that there is indeed a notable distinction between parcels within built-up areas (M = 0.10, SD = 0.22) and those of rural areas (M = 0.35, SD = 0.85) with a significance level of $p > 0.05$. These results lead to the rejection of the null hypothesis (H0), which suggests no significant difference between parcels and instead acceptance of the alternative hypothesis (H1) that there is a significant difference between built-up and rural parcels regarding the registered and calculated surface areas.

Table 4.4 Results ANOVA test for built-up parcels

Group	Obs.	Mean	S.D.
Selected	6252956	0.10	0.22
Unselected	1959602	0.35	0.85

Do Means Differ? (ANOVA)

D.F.	8212556
F-val	436158.56
p-val	0.000

Table 4.5 Results ANOVA test for Verblijfsobject parcels

Group	Obs.	Mean	S.D.
Selected	5342476	0.11	0.26
Unselected	2870082	0.26	0.71

Do Means Differ? (ANOVA)

D.F.	8212556
F-val	177690.04
p-val	0.000

4.2.2. Woonfunctie and Natura2000 areas

The two other selections of parcels in this research area are parcels with the variable Woonfunctie and Natura 2000 areas. The Woonfunctie variable includes parcels containing a unit with a residential function, which allows for identifying the potential impact on homeowners. The Natura2000 parcels are selected because a general visual inspection shows that areas in the Natura2000 have a high difference between the calculated and registered surface area.

The selection of parcels with a Woonfunctie and Natura2000 parcels shows that around 51.2% % of the parcels in The Netherlands contain a unit with a residential function (N = 4205763). While in comparison, only around 0.1% of parcels are inside Natura2000 areas (N = 86720). A visual inspection shows that the mean relative size of the selected parcels is larger for parcels containing Natura2000 areas. These areas contain the Dutch National Park, the Veluwe, and the IJsselmeer. Selections are also shown in Figures 4.4 and 4.5 below.

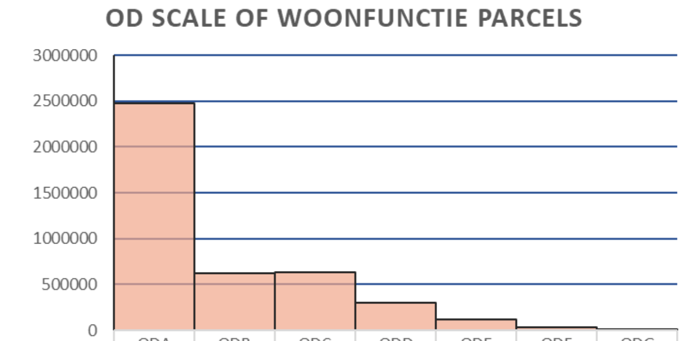
Figure 4.4 Selected parcels with a Woonfunctie

Figure 4.5 Selected parcels within Natura2000 areas

The histogram, including ANOVA results of the Woonfunctie, shows a similar pattern to the selection of Verblijfsobjecten: The OD histogram shows that relative spread has not changed between parcels with a Verblijfsobjecten, Woonfunctie and built-up areas. Furthermore, the mean M-value and standard deviation (Mean = 0.10, SD = 0.22) are the same for parcels within built-up areas. This means that the mean M-value of parcels with the Woonfunctie variable cope with the requirements set by the Kadaster; they cope with the set classification of ODC. This similarity might indicate that parcels with significant discrepancies in area are parcels outside the built-up area and do not contain buildings.

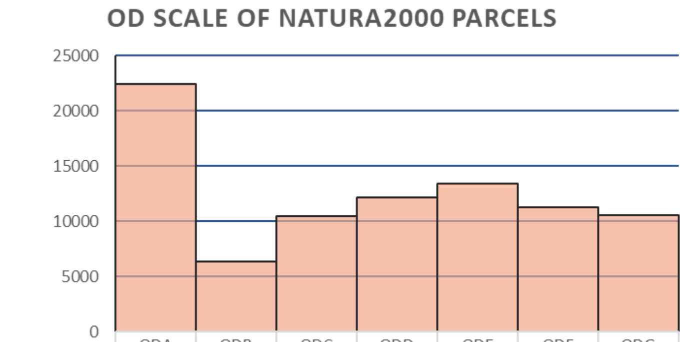
The Natura2000 selection gives a different result from the earlier three selections of parcels. The diagram shows that a large percentage of the parcels are within the higher OD categories. This is also seen for the mean M-values for parcels within Natura2000 areas (M = 0.77, SD = 1.75); these parcels have a mean M-value just inside the limit set for rural areas when the OD category is applied. However, the standard deviation of 1.75 shows that the values differ significantly and might indicate outliers in the data. Parcels not part of the Natura2000 parcels (M = 0.16, SD = 0.43) show a similar M-value to the mean M-value of the current Cadastral Map. This can indicate that some outliers are located inside the parcels in the Natura2000 areas. The results of both selections are shown in Tables 4.6, 4.7, 4.8 and 4.9.

Table 4.6: OD distribution of Woonfunctie parcels



	ODA	ODB	ODC	ODD	ODE	ODF	ODG
Frequency	2479158	622986	629312	304933	119025	38128	12221
Percentage	58,9%	14,8%	15,0%	7,3%	2,8%	0,9%	0,3%

Table 4.7: OD distribution of Natura2000 parcels



	ODA	ODB	ODC	ODD	ODE	ODF	ODG
Frequency	22454	6390	10469	12213	13400	11254	10540
Percentage	25,9%	7,4%	12,1%	14,1%	15,5%	13,0%	12,2%

Table 4.8 Results ANOVA test for Woonfunctie parcels

Group	Obs.	Mean	S.D.
Selected	4205763	0.10	0.22
Unselected	4006795	0.23	0.63

Do Means Differ? (ANOVA)

D.F.	8212556
F-val	148125.42
p-val	0.000

Table 4.9 Results ANOVA test for Natura 2000 parcels

Group	Obs.	Mean	S.D.
Selected	86720	0.77	1.75
Unselected	8125838	0.16	0.43

Do Means Differ? (ANOVA)

D.F.	8212556
F-val	145319.29
p-val	0.000

4.2.3. Governmental agencies

The final selection of parcel types is based on governmental-owned parcels; this selection is essential for the Kadaster because they foresee more leeway for governmental parcels in case of significant changes in parcel size. Governmental parcels could also be used as a buffer to lessen the impact of KKN for parcels with private ownership. For example, boundary changes between private and public parcels can be corrected in favor of private parcels. The correction can be done by offsetting the disparity between the registered area and calculated surface area of private parcels by including the calculated surface area of public parcels.

The selection shows that around 11.1% of the parcel in the Netherlands (n = 8212558) can be specified as governmental owned (n = 821022). However, the selection map indicates that the governmental parcels are of greater size than those of private owners. The histogram shows a relatively higher drop in parcels in the first OD class. Furthermore, the histogram shows that the third largest group of parcels can be categorized as OD class ODG. The high proportion of ODG can also be seen in the mean M-value (m = 0.25, sd = 0.89). This is significantly higher than the (m = 0.16) national average and would fall within the ODD category. The non-governmental parcels, however, have a lower M-value (m = 0.15, sd = 0.40) and fall within the ODC category. The result is shown in Figure 4.6 below.

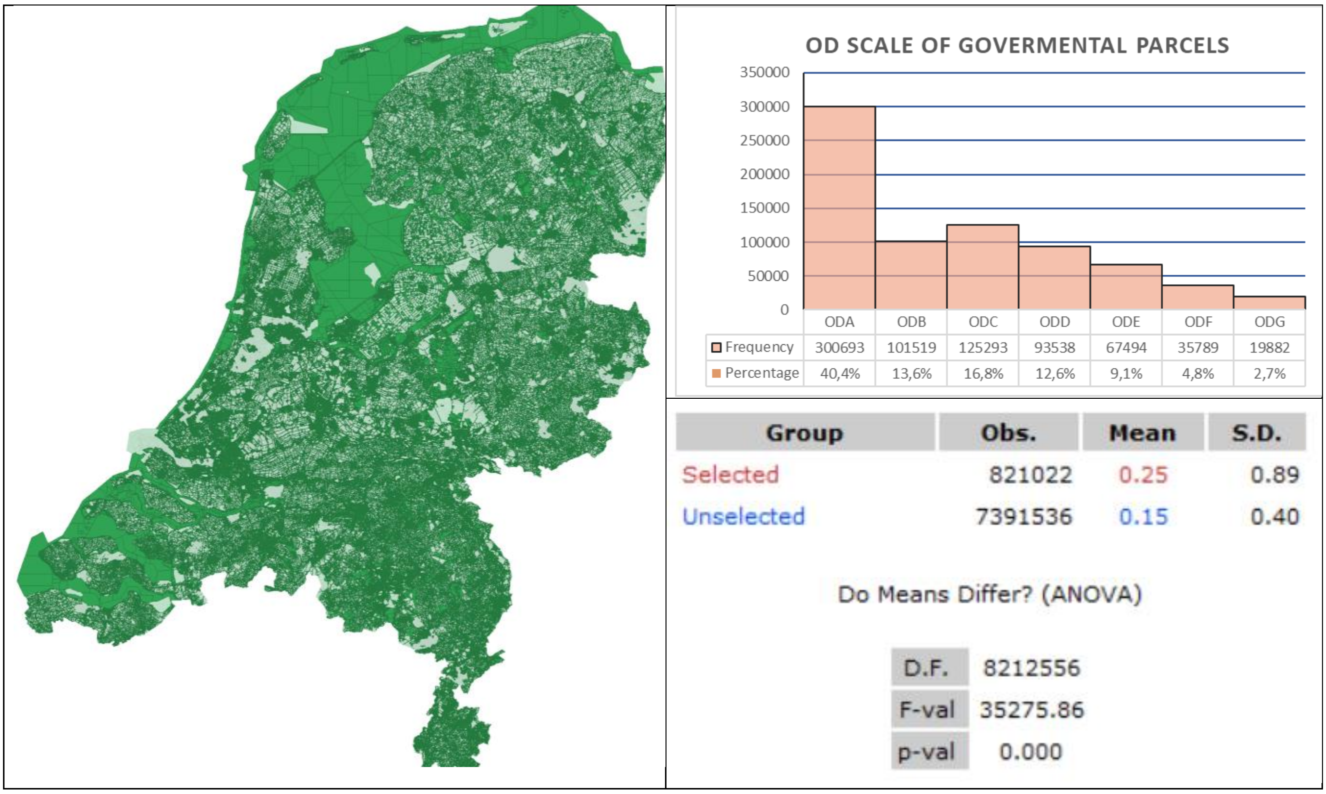


Figure 4.6 Governmental parcels in the Netherlands, histogram of OD categories and values of governmental parcels and the ANOVA results.

4.3. Impact visualization of KKN for the Netherlands as a whole

Another way to identify the impact of the KKN is a visualization of deviations in parcels on a map. Relevant attribute data can be used to visualize the parcels' impact, area differences, and spatial relations. The base impact is measured using the earlier specified visualizing technique around OD classes. The values can be aggregated on a smaller scale level to allow for better impact identification of provinces, municipalities and sections of the Cadastral Map which are potentially the most impacted. This, in turn, allows for a better selection of impacted parcels in the dataset, which is especially important in the case of 8 million parcels.

The impact is visualised by generating a map based on the OD classification. The map gives an overview of the Netherlands and shows the individual OD category of each parcel in the Netherlands. Applying the OD classification to the result shows that certain regions with parcels are more impacted than others; however, on a scale of 1:1650000, it is not possible to differentiate between individual parcels. Changing the scale to a lower level is necessary to identify outliers in different areas. However, aggregation can be used to find impacted areas, sections, municipalities, and provinces with, for example, the mean M-value of the aggregations.

The OD classification's visualization uses the same colours set by the OD table of the Kadaster. This allows for a more straightforward interpretation of the results; furthermore, the red and green palette can be used in this case. Because the colours are used to specify the potential error of parcels, however, the colour scheme has a downside for people who are colourblind, meaning that an alternative colour scheme might be necessary. Lastly, visualizing on a national scale requires the removal of the parcel borders because, on a larger scale, the lines scale to cover the parcel themselves completely, as shown in Appendix 1c.

An alternative colour scheme can also combat colour blindness, reduce the direct association with quality and allow for better identification of different colour steps. A multi-hue is applied for better class differentiation due to extra class contrast. Furthermore, a blue hue has been chosen because people can more easily discern the colour blue up to around eight steps, which is improved further with an added yellow colour for contrast (Kraak & Ormeling, 2020). The colour range also applies a light colour for low values and a dark colour for high values to keep the sequential nature of the data (Brewer, 1994). The visualisation results are shown in Figures 4.7a and 4.8b below and Appendixes 1a and 1b.

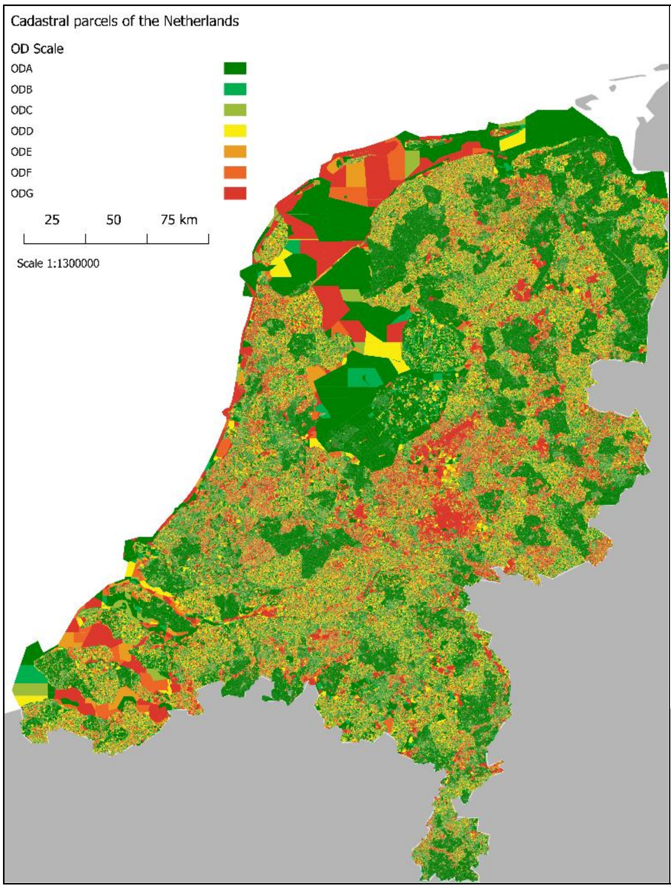


Figure 4.7a Map of the Netherlands based on the OD scale

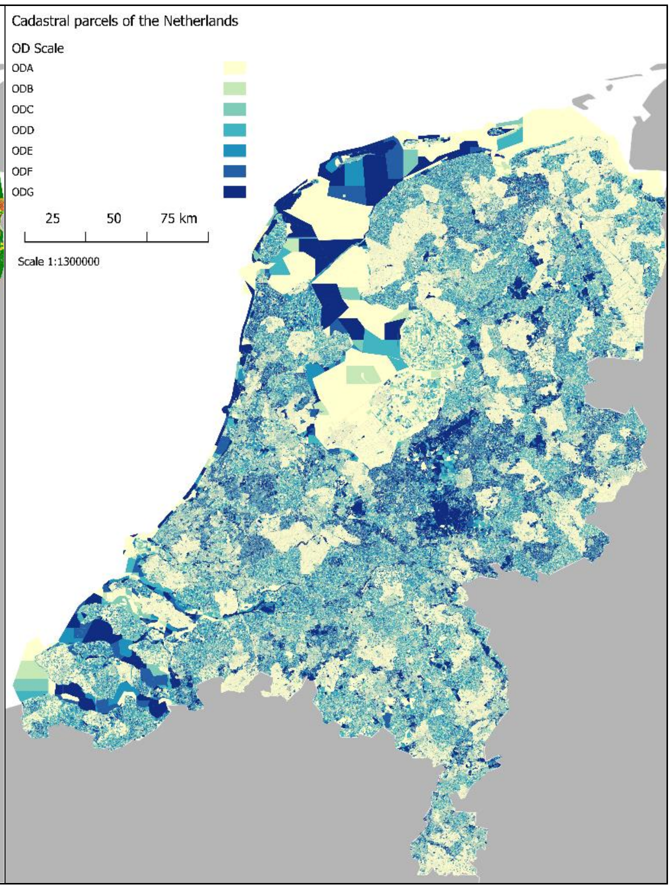


Figure 4.7b OD-map of the Netherlands based on the colour scheme of colour Brewer (1994).

Visualisation A.1 shows a few spatial patterns of the parcels and their OD-value. In this visualisation, the Province of Flevoland can be identified easily. The area has an OD value ranging mostly between ODA and ODB, with most having a contiguous ODA colour. The coastal area of the Netherlands is also clearly visible; as earlier noticed, the coastal water is high outliers with an M-value higher than three times the standard deviation. Other outliers are areas, such as nature parks in the Netherlands, primarily the Veluwe, and the nature parks in the province of Drenthe and the Biesbosch.

Figure A.1 also shows other contiguous areas with an ODA value. One example is clusters of green in the countryside of the province of Groningen and the south of the province of Utrecht; inspection shows that there is land consolidation of agricultural parcels. Other agricultural areas show a similar low OD value. However, some agricultural areas have a more spatially random OD value for their parcels.

Other areas with a low OD value are parcels along the estuary of the Eems. The estuary parcels have an M-value close to zero. The low might be explainable in the border disputes between the Netherlands and Germany. The border dispute may require more precise boundary and area measurements; this effect is not seen in other river estuaries. However, identifying clusters and other patterns is not easy on this scale, so a lower scale or aggregation might be necessary.

4.4. Spatial autocorrelation of the parcels of the Netherlands

Unearthing the spatial patterns of potentially impacted parcels is possible through spatial autocorrelation. Using local spatial autocorrelation, parcel clusters and other spatial patterns are identifiable. To be more precise, it visualises the spatial correlation of parcels in comparison to their neighbours and the significance of this correlation. This means that neighbouring parcels with a significant positive correlation are related or dissimilar in the case of a significant negative correlation. The local autocorrelation is done using Local Moran I; this result is shown in maps 4.8 and 4.9 below.

The resulting map 4.8 shows the clustering of values; see appendix. The scatter plot shows that the complete dataset of parcels has a Moran's I of = 0.193, which indicates that parcel M-values are mostly random from the mean. However, there is a weak clustering of similar values, which means that the M-value of parcels is spatially random distributed throughout the Netherlands with a small amount of clustering.

The clustering and significance map show that most parcels surrounded by parcels with a varying M-values (N = 6072561 and p = 0,05) do not significantly correlate with their neighbouring parcels. While around (N = 458998) parcels are specified as High-High, these are parcels surrounded by other high M-values. The inverse is for parcels with a Low-Low (N =1438296) value surrounded by other low-value parcels. High-Low (N = 28925) specifies that high M values surround parcels with a low m value. Lastly, Low-High (N = 213804) specifies that low M-values surround parcels with a high M-value. The numbers are also displayed in table 4.10

Table 4.10 Matrix of the result of the spatial autocorrelation.

	High	Low
High	458998	28925
Low	213804	1438296

This means most of the parcels neighbours in the Netherlands have a completely random M-value and are not spatially related. However, the Low-Low category shows that 18% of the parcels have an M-value similar to their neighbouring parcels. New and better measurement techniques and requirements for land consolidation and area planning might explain the 18%. Inaccurate or wrong measurements can explain the low number of parcels with high-low relation, because it would not be logical for parcels with high M-value to be surrounded by parcels of low M-value. The low M-value of the surrounding parcels would indicate a high-quality boundary because of a relatively low difference in area.

The low-high relation might indicate that a small part of the parcels has a lower M-value and that they are surrounded by higher significant M-value parcels. This could mean that the parcels with the lower M-value are measured correctly but that the surrounding parcels have a wrong-registered area or were not updated with the measurement of the low parcel. Lastly, the High-High relation indicates clusters of parcels with a high M-value. This might indicate that these areas are of lower quality or still use older measurements for the registered area, which means that they were not revised to the quality set by the Kadaster.

The visualization of the map shows the clusters of parcels; however, the scale makes it hard to find the intricate details. It is still possible to discern clusters of High-High in the Wadden Zee, Veluwe and the Zuid-Hollandse delta and Zeeuwse Delta. Low-low clusters can be seen in the Flevopolder, Veenkoloniën, and various agricultural areas. The scale, however, does not allow for easy identification of Low-High, High-low parcel clusters and parcels with no significant local spatial relationship. It does not easily show the not Significant parcels, even though they are the majority. The non-significant parcels are a large share of the total parcels but have a small share in the area.

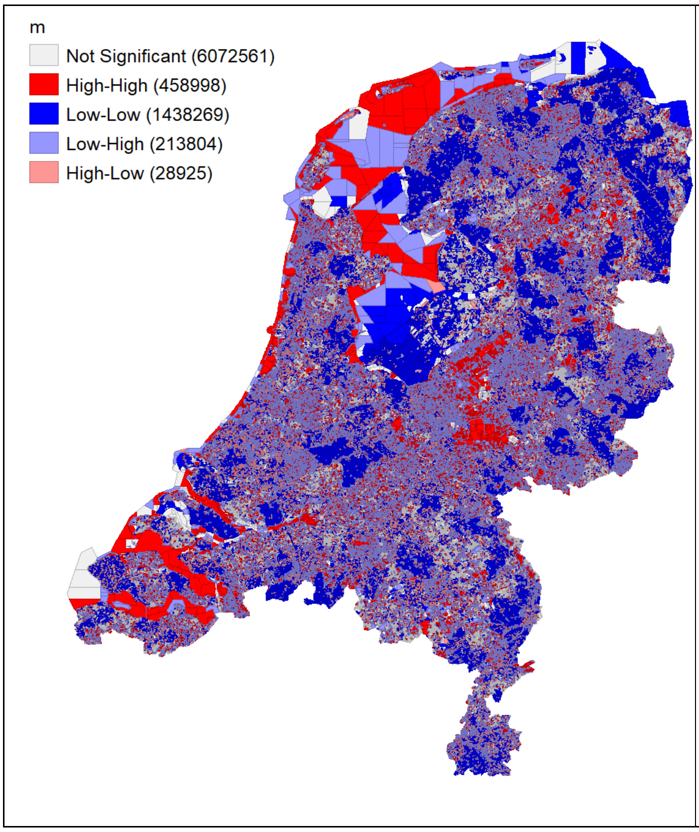


Figure 4.8 Clustering of the parcel M-value in the Netherlands

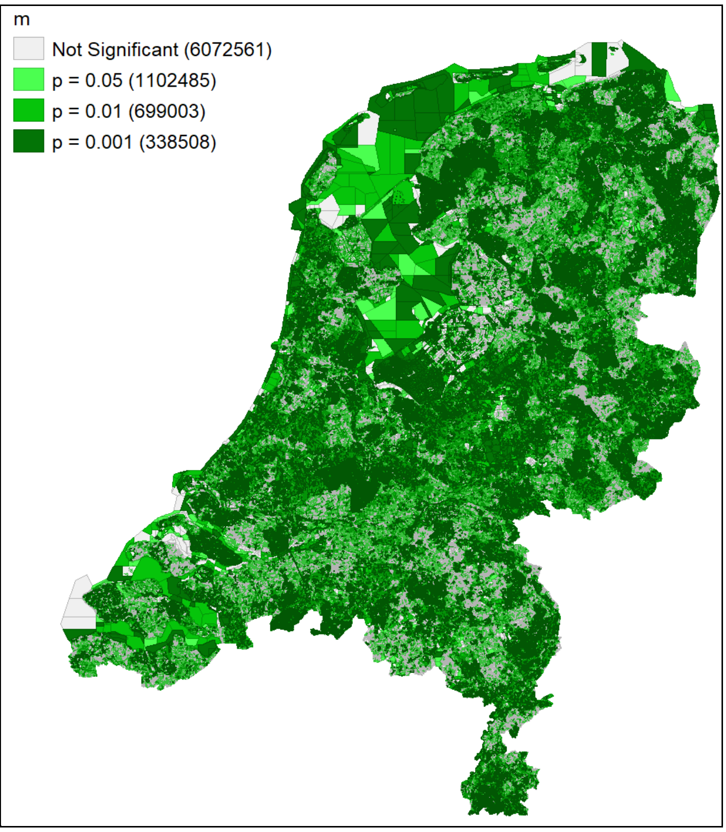


Figure 4.9 Significance map of the parcels in the Netherlands, the different p values illustrate when there is a significant spatial relationship.

4.5. The negative and positive pairing of parcels

The next part of this research tests the assumption of heterogeneity of parcels to verify the hypothesis that *Changes in a parcel's surface area likely mean that another surrounding parcel's surface area changes opposite, to compensate for the change in the surface area.*. This test is done using the Joint Univariate Local Join Count Statistics, which allows testing for heterogeneity of parcels with binary data. In this approach, parcels with a negative change are displayed as 0, and parcels with a positive change as 1. This is formulated as H0: positive and negative parcels are clustered together H1: parcels with a positive area change have a negative parcel neighbour and vice versa. The assumption is that most parcels in the Netherlands have neighbouring parcels with different areas.

By employing the Joint Univariate Local Join Count Statistics in GeoDa, the analysis reveals that a significant number of parcels in the Netherlands do not exhibit significant clustering (N = 78,384,884). Clusters consisting solely of parcels with either positive or negative attributes (N = 329,997, p = 0.05) represent only 0.4% of the total number of parcels.

Based on these findings, it is possible to reject the null hypothesis (H0) and adopt the alternative hypothesis (H1), which suggests that most parcels with a positive change in their surface area have neighbouring parcels with a negative change and vice versa. This implies a compensatory relationship between adjacent parcels in response to changes in surface area. Neighbouring parcels likely adjust their surface area to offset the changes observed in the centre parcel, which could mean that the boundary isn’t in the right location. An example of the pattern is visualised in 4.10a below, and the local joint count results are shown in 4.10b.

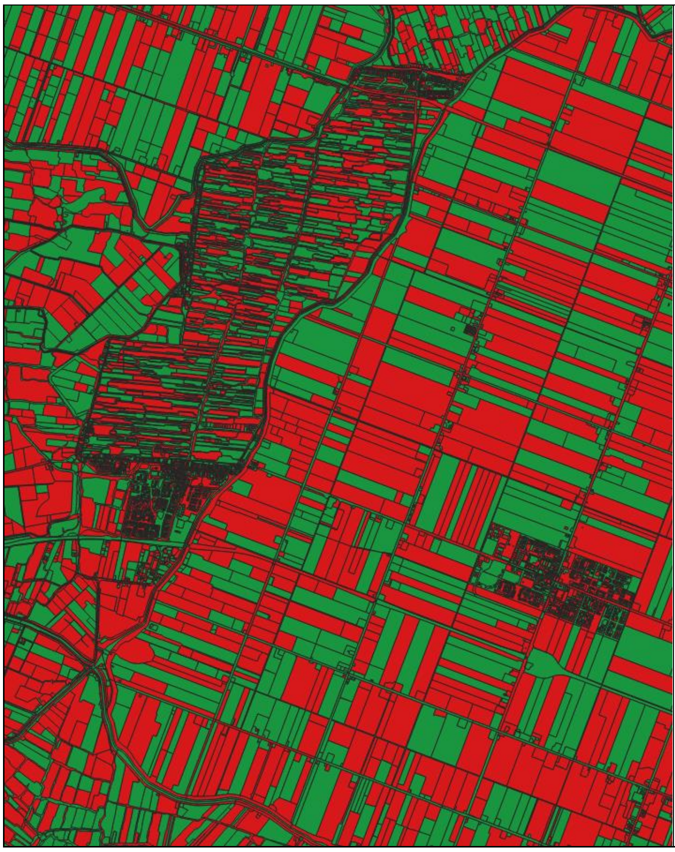


Figure 4.10a Example of positive and negative parcels.

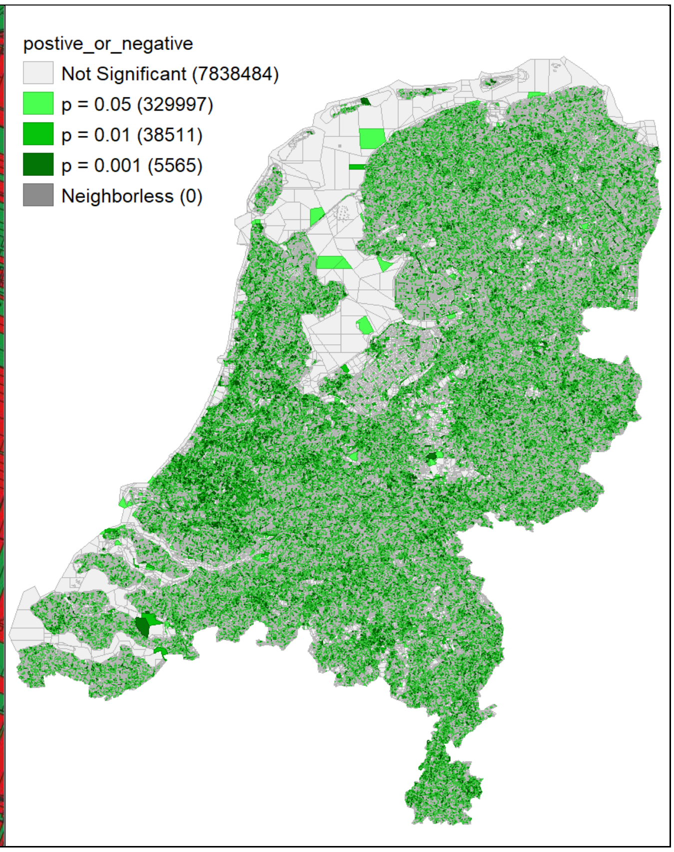


Figure 4.10B Resulting significance map of the joint local count, with the number of significant parcels for each P value.

4.6. Impact visualization of sections and cadastral municipalities

Aggregating the dataset on sections and municipalities yields two new datasets containing the mean and total values of the aggregations in the Netherlands. The aggregation merges the parcels into 854 municipalities and 7703 sections. The aggregation allows for better identifying regions the KKN might impact by identifying significant differences between provinces, cadastral municipalities, and sections.

Visualizing the relative area difference of municipalities shows that most municipalities (N = 818) fall within 1% to -1%. While in comparison, only two municipalities exceed the difference between the two parcels. These two cadastral municipalities are Hagestein and Wassenaar. A cadastral municipality consisting of two stand-alone regions containing a part of the river Lek with the Weir complex Hagestein and the interchange Vianen are significant outliers in area difference. The other outlying municipality is the municipality of Monster, which contains a sizeable coastal parcel with a 9.5% difference in size.

Applying the exact visualization to cadastral sections also shows that the majority (N = 7236) of sections fall within 1% to -1%. While around (N = 15 for -2-3%, N = 47 for 2-3%), 62 of the sections exceed a difference of 2%. These sections are for a part situated next to or contain parts of the rivers in the Netherlands and are located on floodplains of the river. However, they can also be seen in old city center sections, like the center of Leiden, Delft, Schiedam and, to a smaller extent, Amsterdam, Gouda, and Groningen. Furthermore, each section has a calculated surface area larger than the registered area, and only the city center of Alkmaar has a difference smaller than -2%. Lastly, the data also shows a cluster of parcels with a difference more significant than 2% in the village of Nieuwveen. The visualization is also illustrated in Figures 4.11 and 4.12.

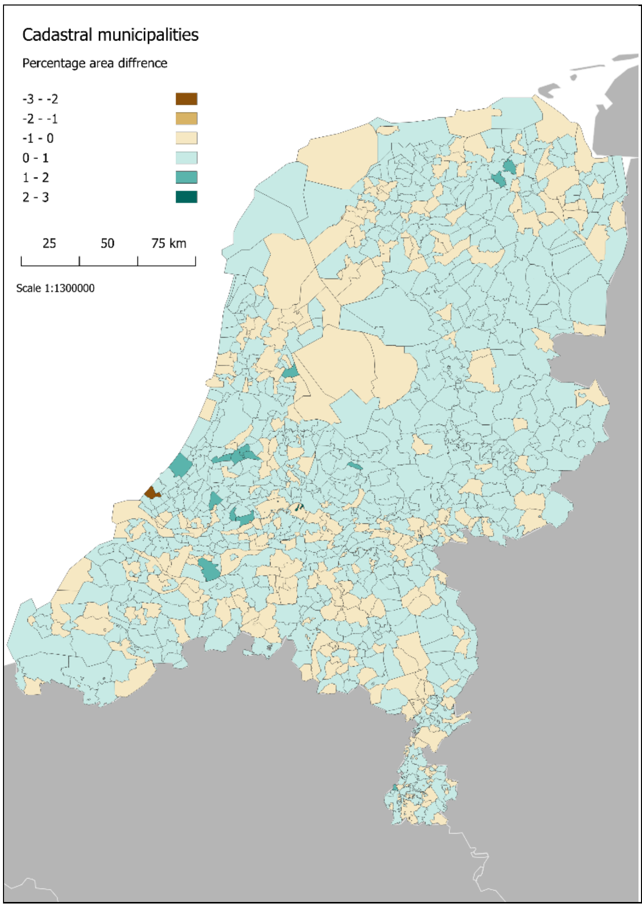


Figure 4.11 Absolute area difference of cadastral municipalities

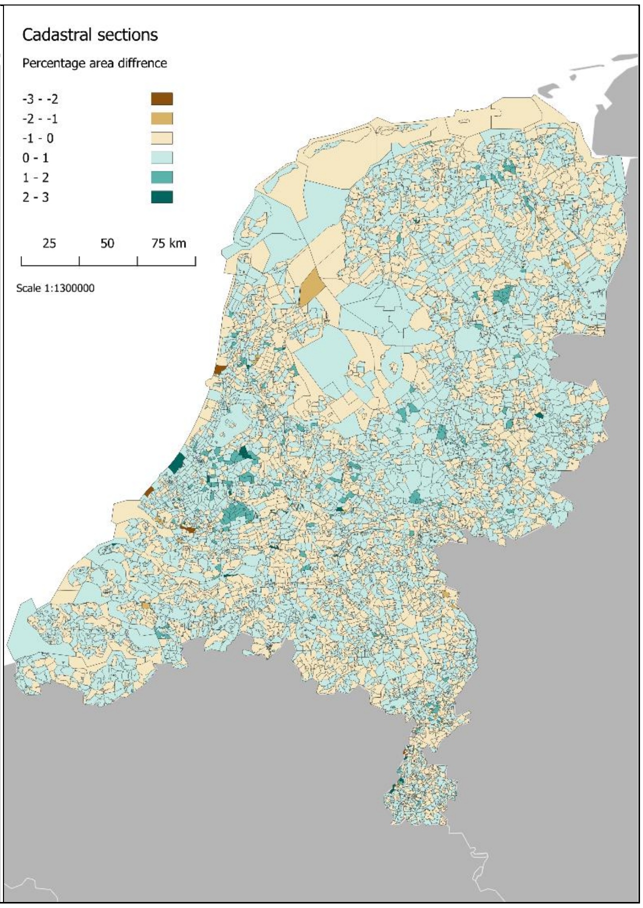


Figure 4.12 Absolute area difference of sections

The aggregated mean M-value allows identifying regions with a relatively large difference between the registered and the calculated surface area. It allows for better identification of outliers and the quality of the parcels. The resulting maps 4.14 and 4.15 shows the aggregated mean M value for the whole of the Netherlands.

The map shows that 69 sections fall in the ODG category, and 374 fall within the ODF category. This indicates that (N = 7703) 5 % of the sections exceed the quality limit set by the Kadaster. The map shows visually that sections in nature areas have a higher OD value. Furthermore, a pattern is visible for cities with older city centres. Where the OD categories of inner-city sections are lower than surrounding ones, this might be explained by the centre sections containing parcels of a lower quality or still having older measurements. The parcels next to the city centre have a higher quality. Applying a univariate local Moran's, I (I = 0.023) to the section's dataset show that M-value is spatially random. This pattern is shown in Figure 4.13.

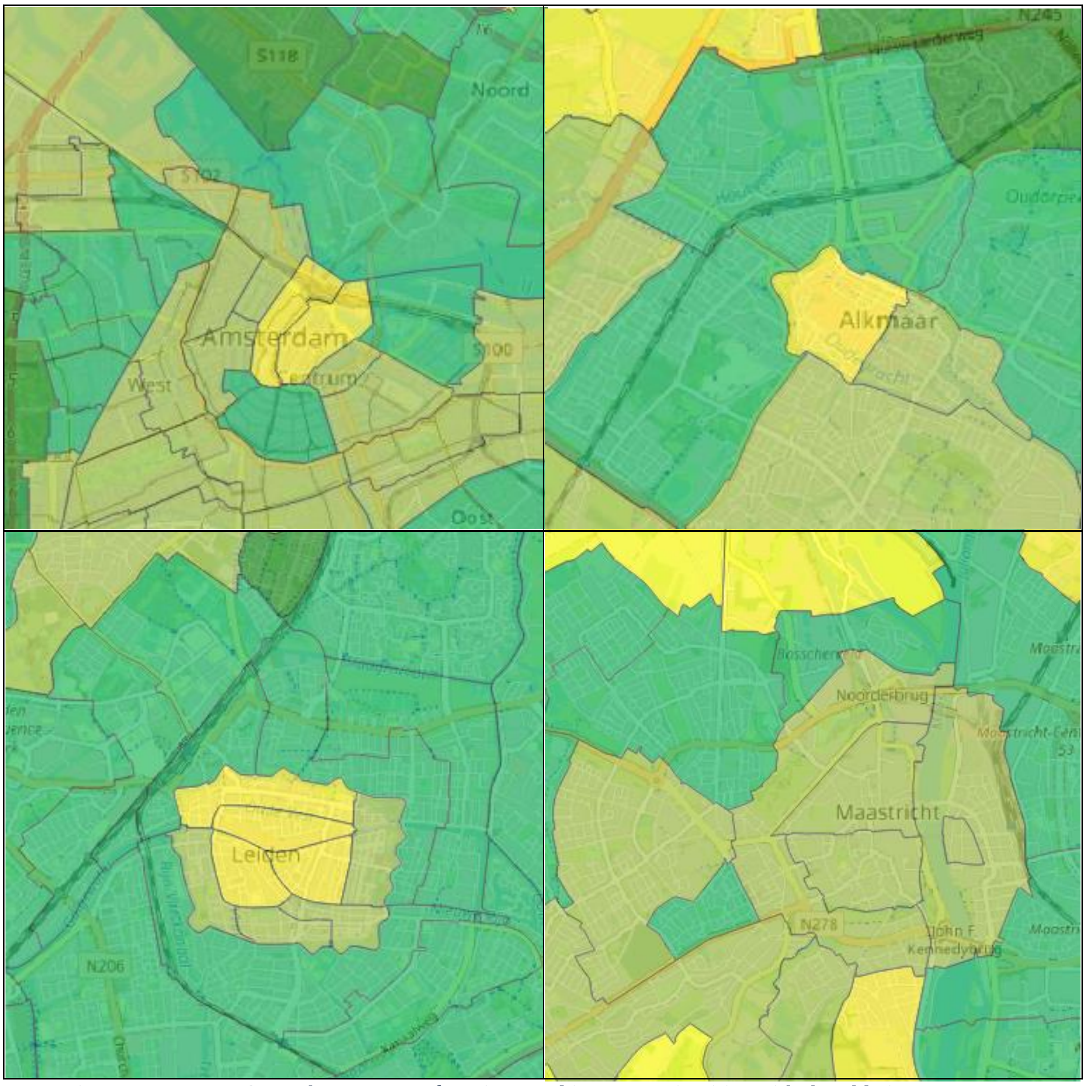
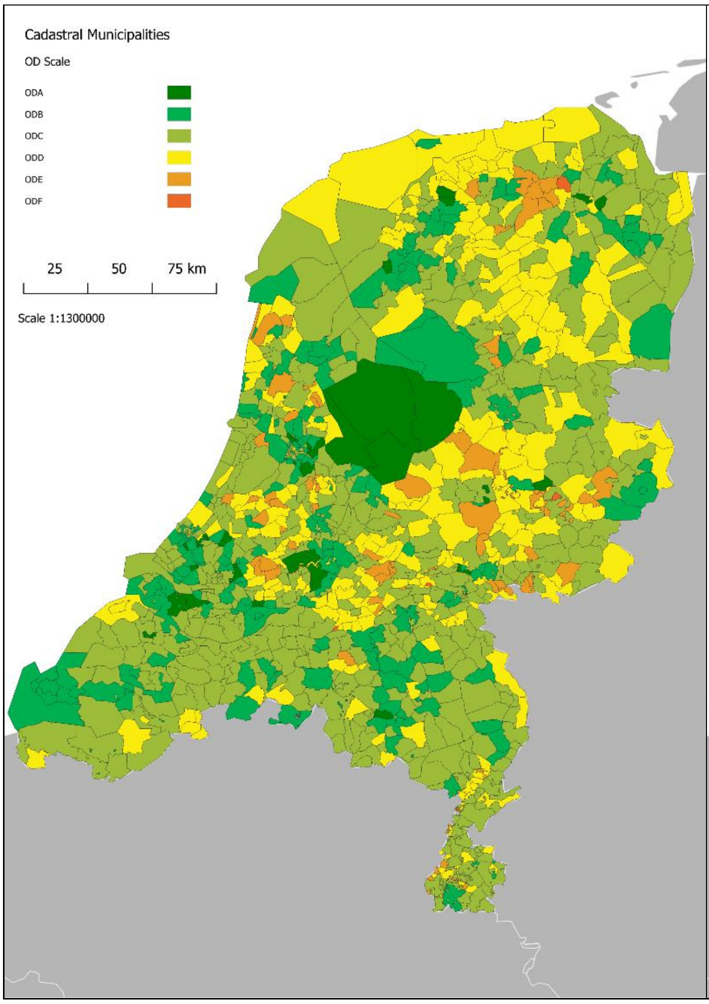


Figure 4.13 Mean OD-value Pattern of sections and its pattern in cities with the old city centre

The cadastral section boundaries can also be compared with the OD parcel map. For example, the land consolidation of the area near Vianen shows that the boundary precisely ends on the border of the cadastral section. Furthermore, small sections containing a village like Lopik and Cabouw still have a higher OD value than the neighbouring sections. The villages have an ODD value, while the surrounding sections and parcels are almost all ODA. This indicates that the land consolidation did not consider sections with no agriculture function. In general, however, sections within cities and villages have a lower M-value in most cases than the neighbouring parcels.



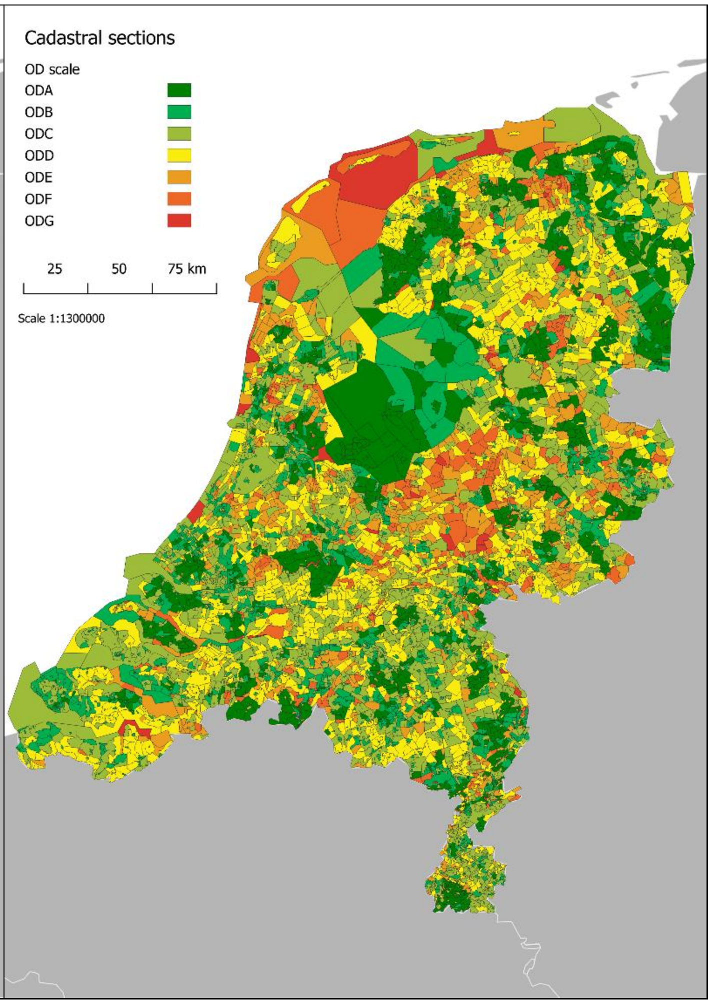


Figure 4.14 Mean OD value of parcels in Cadastral municipalities

Figure 4.15 Mean OD value of parcels in Cadastral Sections in the Netherlands

4.7. Visualization of the parcel in the province of Utrecht

By visualizing parcels on a larger scale, patterns can be better identified and the impact better measured. This is especially important for smaller parcels not discernable on a small scale. At this scale, it is also feasible to analyze the land type of parcels using codes set in the BBG. This gives a general overview of the map and the significance map based on the local Moran's I.

The OD scale map of the province of Utrecht shows a few patterns, as shown in Figures 4.17 and 4.18. Firstly, the Utrechtse Heuvel rug is visible on the map, which is positioned in the middle of the map towards the southeast, with an OD score ranging from ODE to ODG. However, the highway and the villages are islands inside the dataset with low OD values. Another visible aspect is the difference between agricultural land use areas, where some sections have a positive spatial autocorrelation of low values. In contrast, other agriculture parcels are a patchwork of lower and higher values parcels. This is also visible in the significance map, which shows a low-low relation (p= 0,001) for the agriculture parcels to the southeast and southwest. A high-high for agriculture parcels above these sections and to the Northwest contains mostly spatially randomly distributed parcels. It also shows high-high relation for the parcels situated along the Lek.

The city of Utrecht shows a spatial difference between neighbourhoods; Parcels in newer neighbourhoods have a positive spatial autocorrelation, as shown in Figure 4.16. In contrast, the city center shows a combination of both high-high and low-high spatial correlations. Lastly, the other neighbourhoods are mostly spatially randomly distributed. The distribution can be explained through the construction history of the neighbourhoods, where the most recent neighbourhoods have a positive spatial autocorrelation with a low-low relationship between the parcels. The older neighbourhoods, however, are spatially random or have a high M-value for the parcels. This can also be seen in the Neighborhood of Leidsche Rijn, where most relations are high-high; however, at the location of the old village, the parcels are randomly distributed and have a generally lower M value. This difference can maybe come from different measurement techniques, the age of the data and or large-scale land measurements.

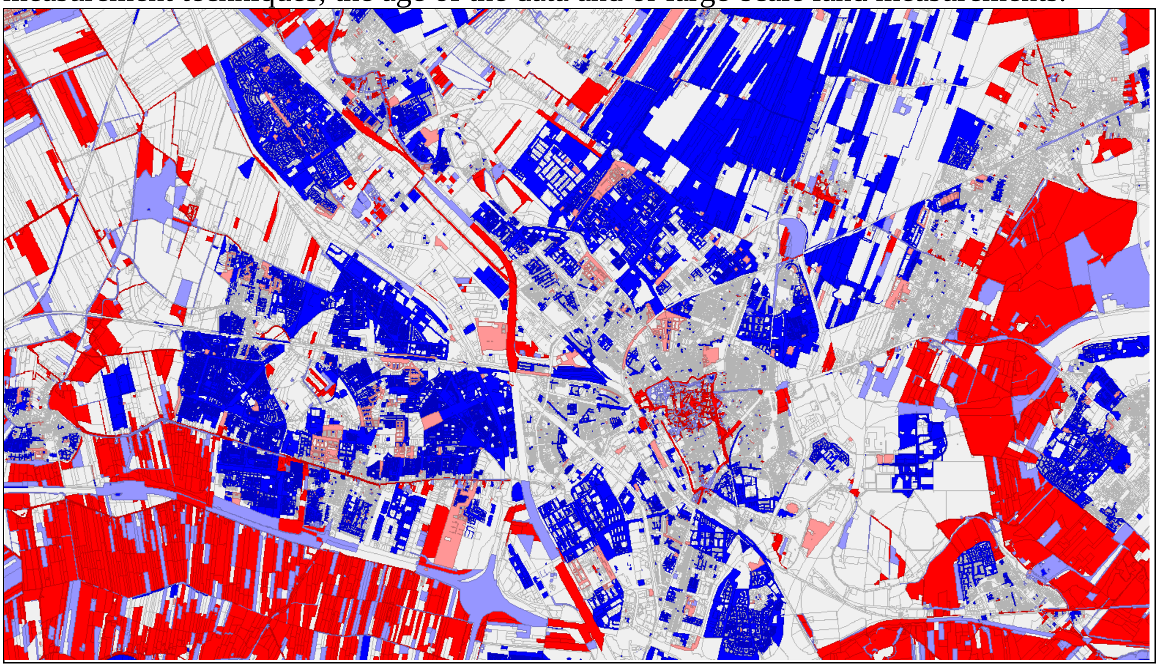
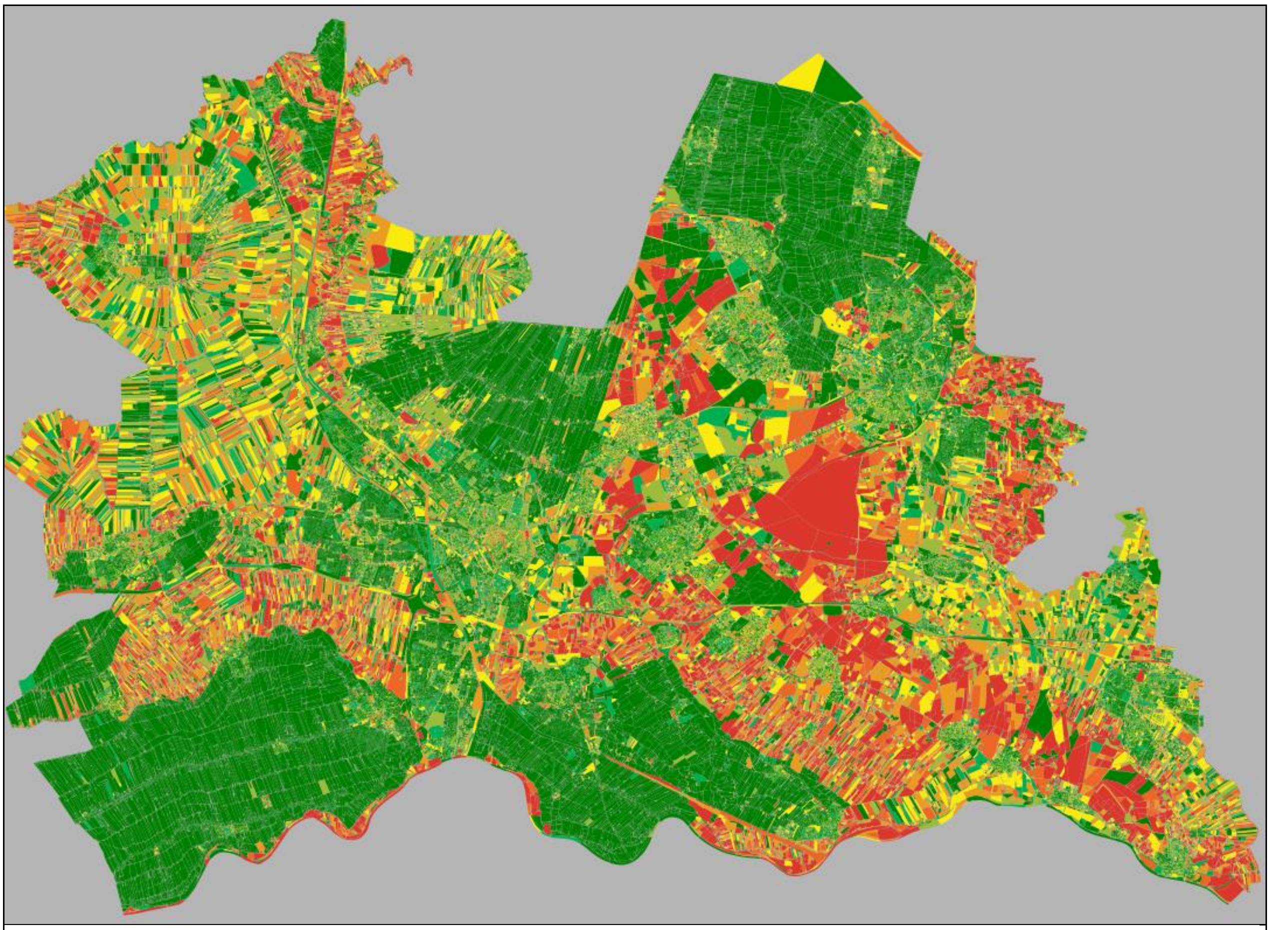


Figure 4.16 Univariate local Moran's I Cluster map of the city of Utrecht.



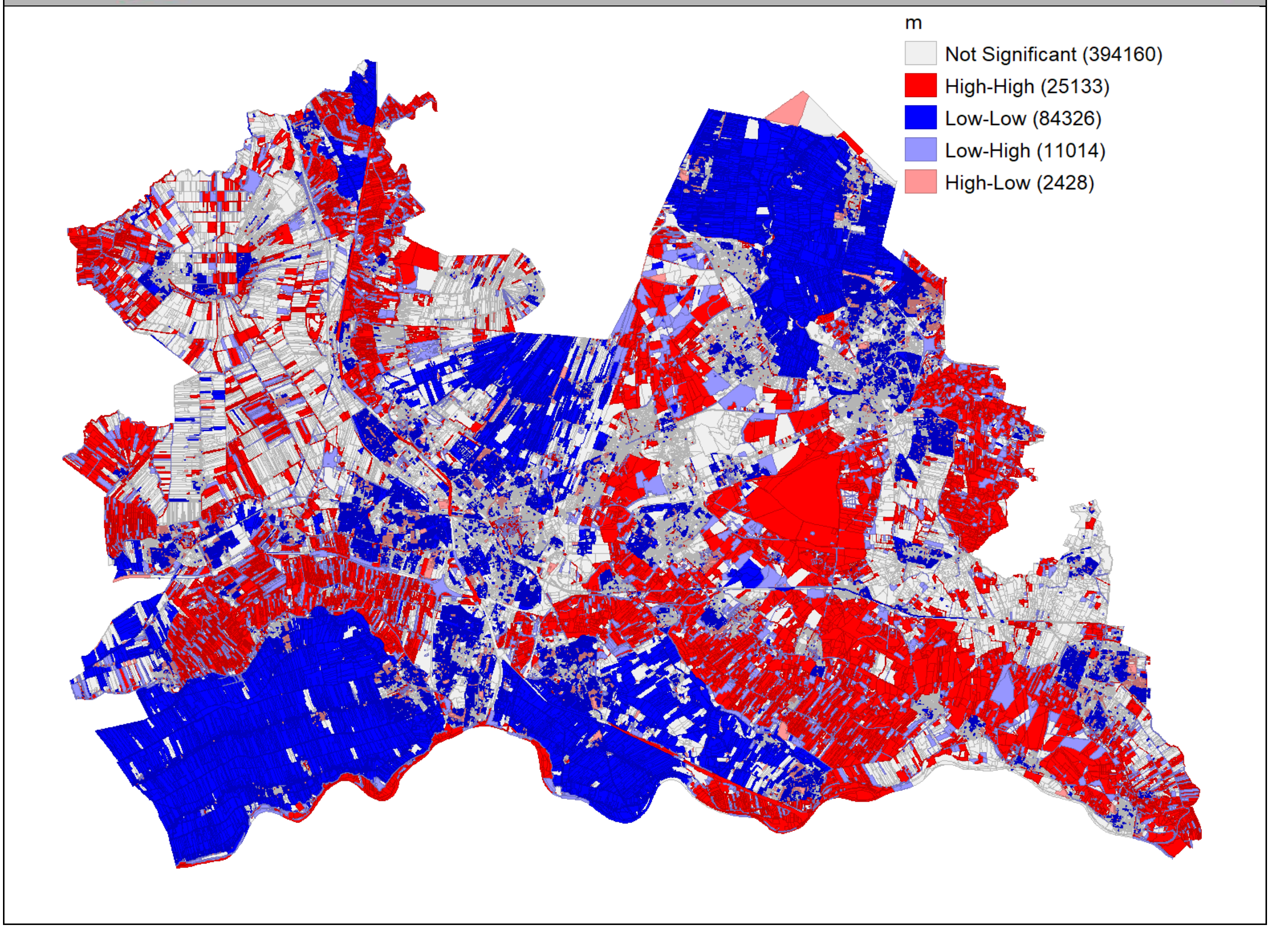


Figure 4.17 OD Map of Utrecht   *Figure 4.18 Moran's I map for the cadastral province of Utrecht.*

4.8. Nieuwkoop

The cadastral municipality of Nieuwkoop is located within the province of South Holland and contains the KKN pilot. The municipality contains 7980 parcels subdivided into six different sections. Based on the BBG, 4420 parcels can be designated as built-up parcels, increasing to 4704, when parcels with industry designation are included. The second highest number of parcels (N = 1667) is designated as agricultural. Furthermore, the center of the municipality contains a lake, which originated from peat harvesting. The BBG selection is also displayed in Figure 4.19, based on the BBG land types.

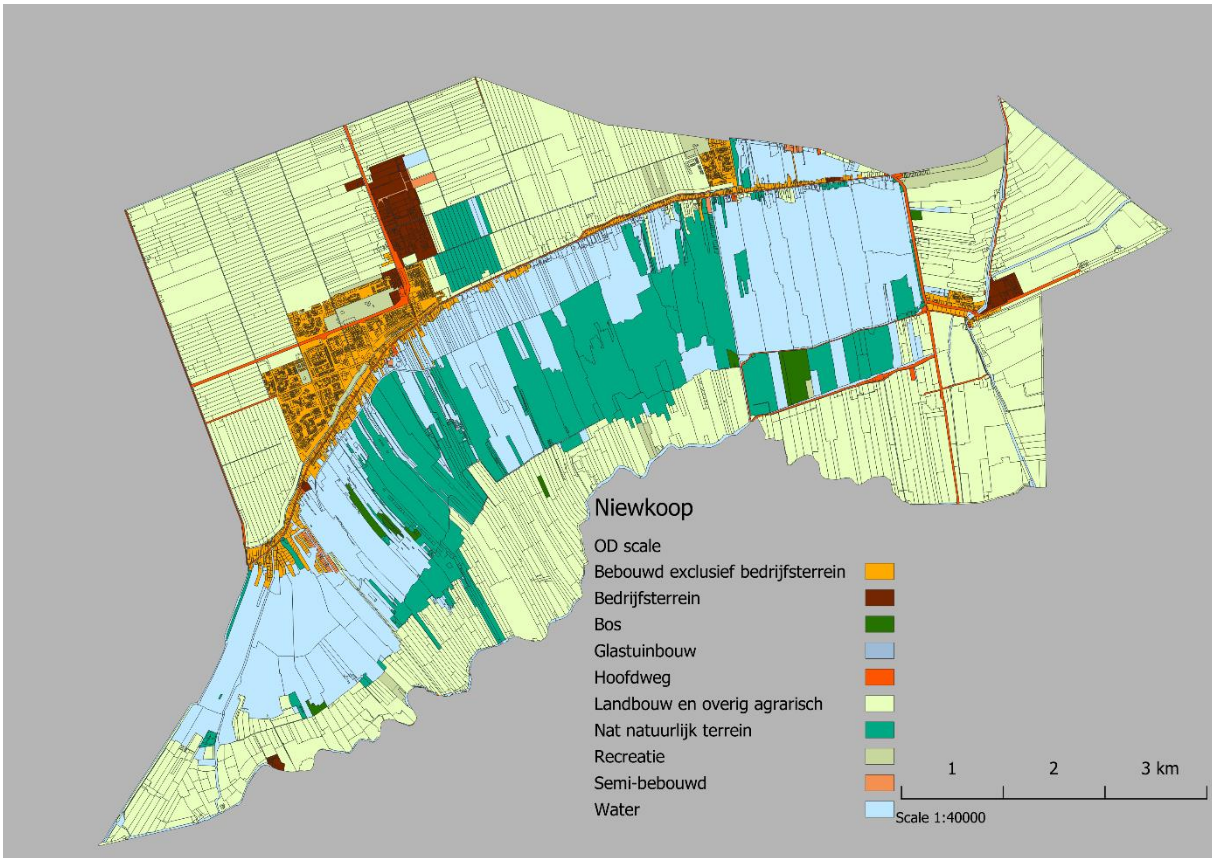


Figure 4.19 Land use of parcels in the municipality of Niewkoop based on the BBG cover of parcels.

Comparing the M-value shows that the region has an average M-value of 0.34 with a standard deviation of 0,62. It is above the Netherlands' average M-value (M =0,15) but falls within limits set by the cadaster for rural areas. When selecting only parcels within built-up areas, the m (M = 0.18, sd = 0,36) value comes closer to the mean M-value in the Netherlands. In comparison, the parcels outside the area have an even higher mean M-value (M = 0.63, sd = 0.87). Most selected parcels have a built-up or industry function, while non-selected have agriculture, water, and nature as land use. The difference is also shown in Figure A.2.

Analyzing Nieuwkoop using the OD-map and the results from the Univariate Local Moran's I show that the villages in the municipality fall into the ODA categories. The village parcels are clustered together with a positive spatial autocorrelation, where they have low/low relation. The roads and the bog areas also have a positive spatial autocorrelation; however, this is a high/high relation. At the same time, a negative spatial autocorrelation value is also seen for 409 parcels, mainly located in the bog areas. Furthermore, 5935 parcels are spatially random ($p = 0.05$); they do not have a similar neighbouring value. The global Moran's I ($I = 0{,}281$) show that most parcels are randomly distributed but lean toward being clustered in pairs of low and high values . The results are shown in Figure 4.20 below and in Appendix A.3 and A.4.

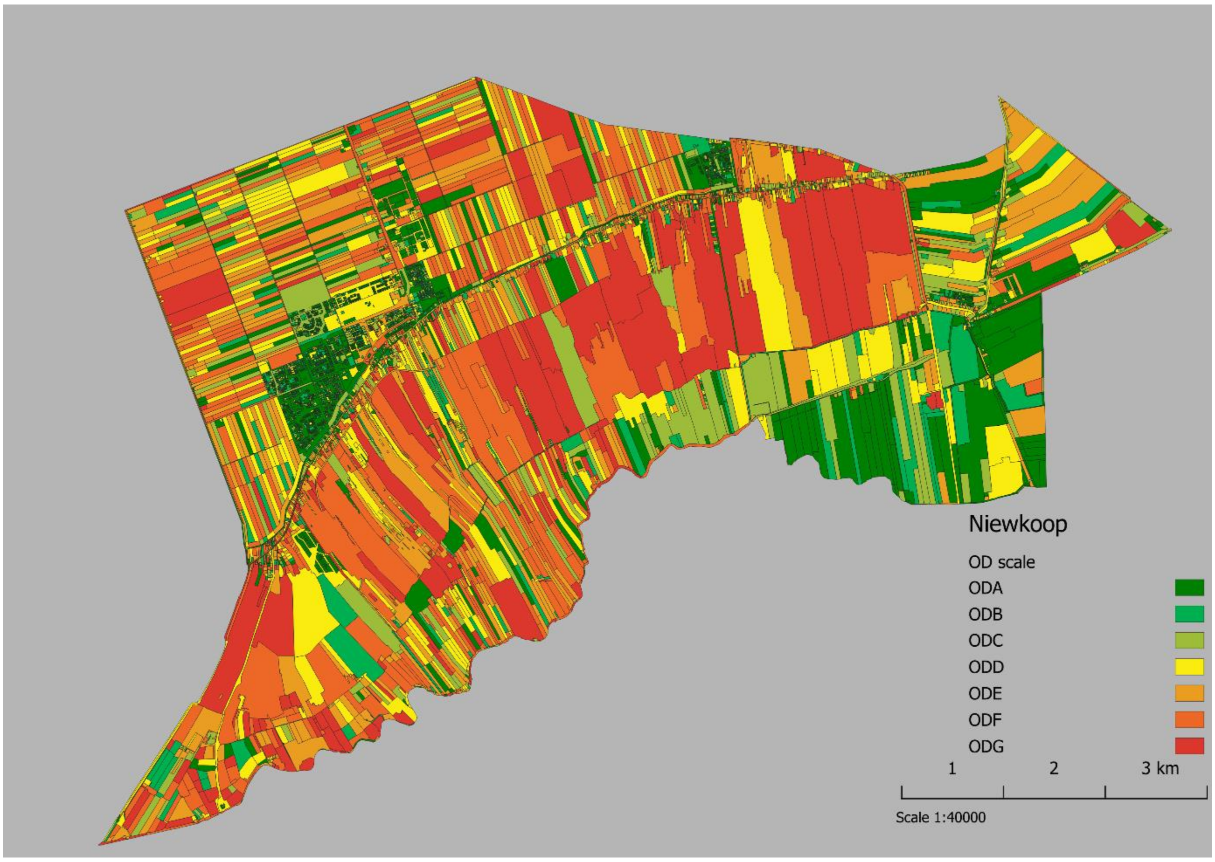


Figure 4.20 OD maps of the cadastral parcels in Nieuwkoop

4.9. KKN pilot

The KKN pilot is only a tiny part of the total Cadastral Map. The resulting parcels have been polygonised and are compared to the new Cadastral Map using the OD classification. However, the limited number of parcels (n = 18) makes it hard to make overall representative conclusions. But comparing it with the surrounding parcels might bring new insights into the spatial relationship of the surface area change. However, the parcel can give an idea about the potential impact of the new Cadastral Map.

When looking at the OD visualization, it is possible to see that the OD value changed for most parcels. Only four parcels improved in OD class, eight decreased in the category, and six stayed the same. The change is also seen in the M-value, for which the mean M-value increased by around 0.16, which means that parcels have a bigger mismatch between the registered and calculated surface area of parcels. One parcel that did change significantly less was the parcel along the Woerdense verlaat, which had a change in M-value of 0.004 and a total area change of -0.13 m^2. The slight change might be explainable by the surrounding parcels, which are all within the ODA classification. The results are shown in Figures 4.21 and 4.22 below.

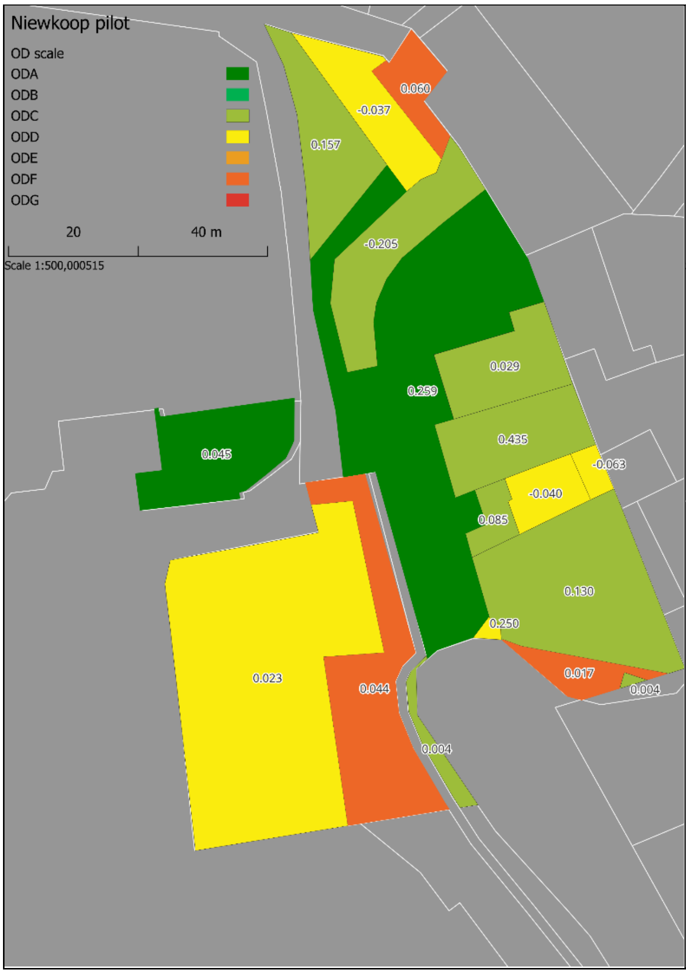


Figure 4.21 Map with the old OD and M-values of the pilot area

Figure 4.22 Map with the new OD and M-values of the pilot area

Comparing the difference in M-values to the OD categories shows a negative trend downwards, where higher OD categories have a lower difference in M-value. However, testing for significance shows no relation at $p < 0{,}05$, with the p being 0.133, furthermore the r^2 value (r^2 = 0.026) shows that the original M-value does not explain the variance of the difference in M-values. Removing the two most outliers in the dataset shows a significant relation at $p < 0{,}05$, with p being 0.045. The removal means that with the outliers removed, the data is significant. However, the observations are not big enough to make a representative conclusion.

Comparing the difference in the M-value of the parcels shows a positive trend upwards, where higher m values have a more significant M difference variable. However, the test shows no significance at $p < 0.05$, where the $p > 0.734$. Meaning that it is not possible to assume the data, and the data does not explain the variance with r^2 = 0.083. Lastly, the tested data only contains eighteen parcels, meaning a larger sample size might give a different result.

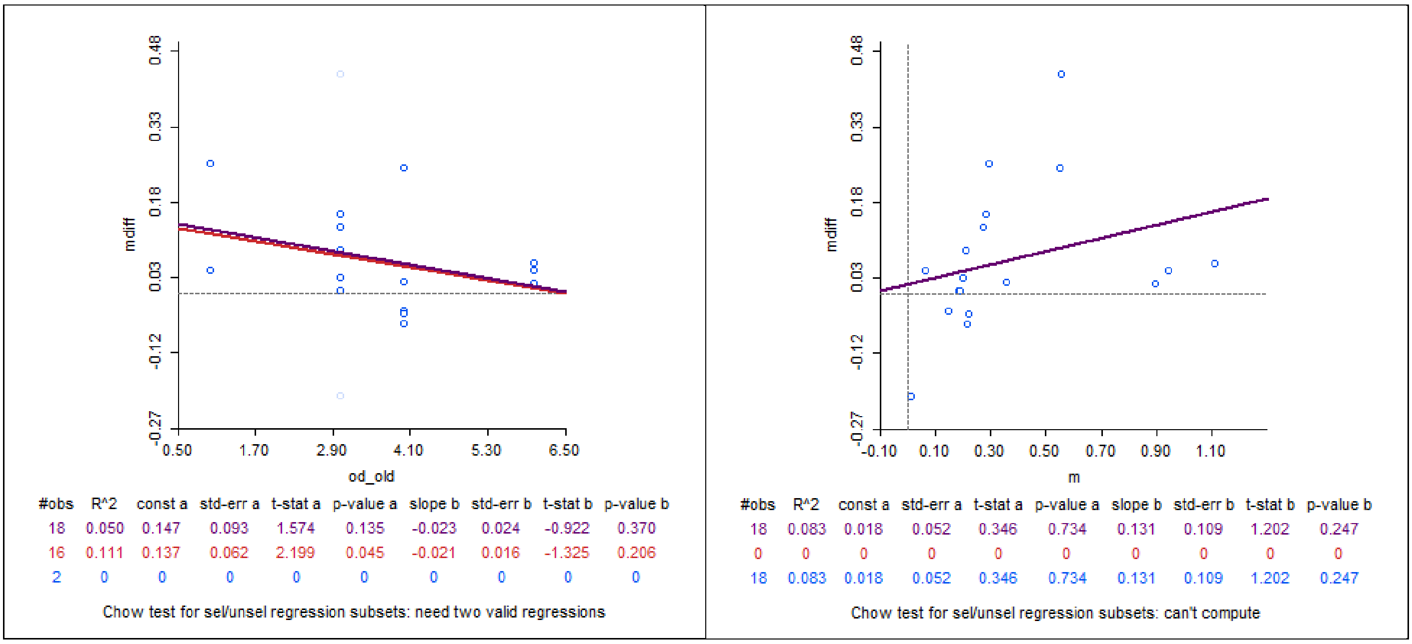


Figure 4.23 Scatter plot of the old M values with the difference in OD categories and the m value.

Another aspect is the change in the area of parcels, which shows that the mean parcel changed in surface area by around -0.27%. However, the total area of all the parcels did increase to 51.40 m^2, which indicates that the larger parcels had a proportionally more significant influence. This increase comes mainly from the two most prominent in the middle of the map. However, the area change has no visible relationship between the original OD categories. With the most significant relative area change for a parcel with the ODA category. The diagrams below also display the changes; see Figures 4.23 and 4.24.

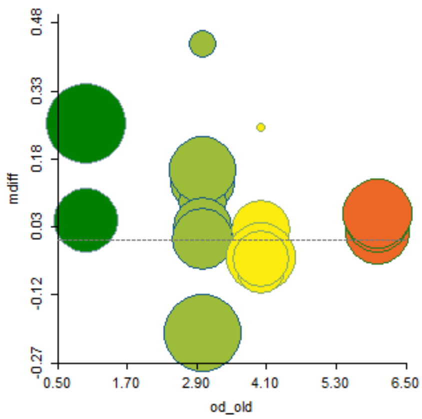


Figure 5.24 Area size and shift in M-value

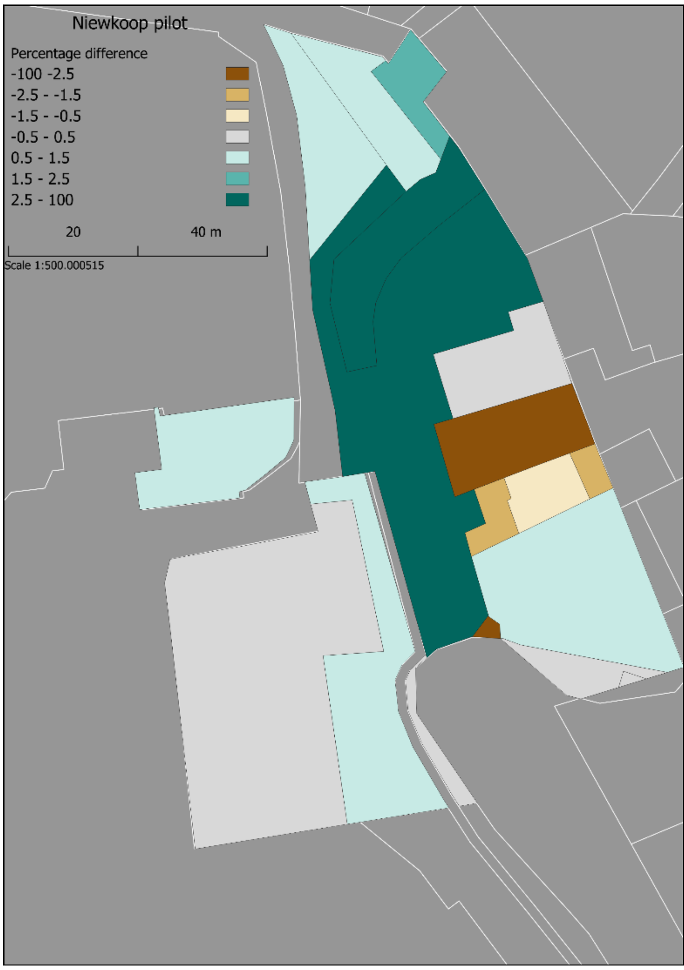


Figure 4.25 Map of the absolute change in area of parcels

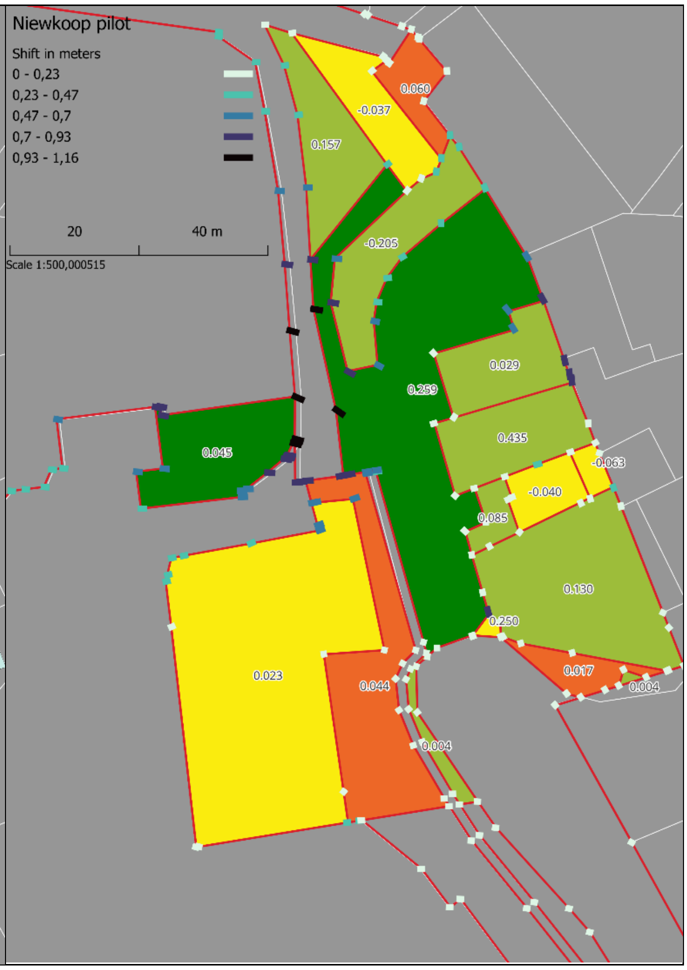


Figure 4.26 Shift in the parcel vertices of the KKN pilot area

Comparing the shift in the map and the OD categories shows that parcels with vertices shifts of around > 0.23 meters are less changed in their M-value. Furthermore, parcels with an ODA value do not necessarily have more minor shifts than parcels of a higher category. The parcels with a combination of different shift categories can indicate a shift in the form of the geometry of the parcel. Furthermore, significant shifts in vertices do not necessarily influence the geometry of parcels if all the vertices move the same way. This is displayed in Figures 4.25 and 4.26.

5. Discussion

This chapter will discuss the results of this research and compare them with information from the literature section of this research. It will try to answer the main research question; *What effect will the implementation of Kadastrale Kaart Next (KKN) have on the area of different categories of parcels, the WOZ value, the willingness of stakeholders in the Netherlands and how to visualize it?* The chapter will be structured along each sub-question and flow into the main research question.

5.1.1. Sub-question 1

This research's first sub-question is: *How will the KKN influence the registered area of the Cadastral Map?*

The current Cadastral Map originated from the initial cadastral measurements of the Netherlands and improved throughout its history through new modifications, improvements, and renovations of the Cadastral Map. These improvements to the map were not always done for each region, and certain regions still use cadastral data from the 19th century (Kruizinga & van Doornmalen, 1997). Furthermore, renovations like the harmonisation with the BGT did not always lead to a better representation of the field sketches (Salzmann et al., 1998). As such, the current Cadastral Map consists of parcels of varying quality, which differ per region and area. The varying quality can be because of older measurements, different measurement techniques, measurement errors or errors in the data.

The literature review also illustrates that the 6th version of the Cadastral Map is a complete overhaul of the current Cadastral Map. The new cadastral uses field sketches and survey documents to remeasure all cadastral boundaries of the Netherlands (Franken & Florijn, 2021; Van Den Heuvel, 2021). According to Hagemans et al. (2021), the KKN changes the registered area of parcels when it exceeds the threshold set by the Kadaster. The quality limits are 5√a cm and 10√a cm in rural and built-up areas, respectively. With the implementation of the new Cadastral Map, a new classification system will be based on the OD classification system. The new classification system require that parcels fall within the ODA specification (Hagemans et al., 2020). The new requirements mean the new Cadastral Map might affect more parcels.

Results from the KKN pilot show that the mean M-value is increased to around m = 0.16. However, there was no significant relation between the original M-value and the difference in the M-value. Furthermore, the data could not explain the variance in the dataset r^2 = 0.083. Bek's formula could not explain the predicted change in the registered area of parcels. The dataset showed that the parcel surrounded by ODA parcels had the slightest change in M-value. Lastly, the dataset showed that the calculated surface area of the parcels changed when the pilot was implemented. However, it is currently impossible to draw any definitive conclusions from the results because of the limited number of observations (n =18) and the pilot only being done for one small section of the Netherlands.

It was possible to identify that parcel with only a slight shift in their vertices and a tiny M-value difference. This means that parcels of low quality can be pre-selected when the parcel has both a relatively large M-value and a relatively small shift in vertices. Improving the current Bek's formula with vertices quality might significantly enhance the prediction between the change in the registered area of parcels and the impact. However, Bek's formula can still be used for measuring the difference between the registered and the calculated surface area.

The results from the hypothesis of *"The registered area of the Netherlands is smaller than the actual calculated surface area of the current cadastral map"* indicates that the registered area is slightly smaller than the measured geometric size, with a difference of approximately 0.078%. A difference in surface area of 32309515 m^2 makes it so that the null hypothesis (H0) is rejected and the alternative hypothesis (H1) is supported. This indicates a disparity in the registered and calculated surface area. This could mean that old measurements still influence the registered area or that errors in the data influence the cadastral map. It would indicate that not only would the boundaries of the parcels change with the KKN, but also that they also change the total surface area or the registered area of parcels.

While the results from the hypothesis of *"Changes in a parcel's surface area likely mean that another surrounding parcel's surface area changes opposite, to compensate for the change in the surface area"*. Indicates that many of the parcels in the Netherlands are not significantly clustered (n = 78384884) of parcels with either positive or negative attributes. While Clusters consisting solely of parcels with positive or negative attributes (N = 329997, p = 0.05) represent only 0.4% of the total number of parcels. This means that the null hypothesis (H0) is rejected, and the alternative hypothesis (H1) is accepted. However, this does not take into account the degree of magnitude of change. The results indicate that there are not many clusters of parcels which all have a negative or a positive change in surface area. A change in surface area means that one neighbouring parcel needs to change with it.

In short, the KKN will impact the registered parcel size in the Netherlands and the geometry of parcels. However, the extent of the impact is not clear. Parcels with an already significant difference in area still have their registered area changes, even if the geometry changes little. Furthermore, no definite conclusion can be made from the Pilot due to the small number of observations.

5.1.2. Sub-question 2

The second sub-question of this research is: *In what way can the parcels of the current Cadastral Map be categorised, and what are their spatial characteristics?*

This research shows multiple ways to categorise parcels in the Netherlands. One way used in this study is based on the Kadaster having different quality and measurement requirements between rural and built-up areas. Rural areas have a lower quality requirement than built-up areas (Polman & Salzmann, 1996). Another way to categorise is by comparing parcels with a Verblijfsobject and Woonobjecten (only residential), which allows for identifying the impact of the KKN on parcels with buildings. Another selection is based on parcels within the Natura2000 areas because Natura2000 areas contain parcels which can use old and inaccurate measurements, for example, areas within river deltas or forests (Kruizinga & van Doornmalen, 1997). The final selection is based on private or public parcels because the Kadaster prefers a low impact on private parcels.

The first selection shows that parcels inside built-up areas have a significantly lower M-value (M = 0.11, sd = 0.22) than rural parcels (m = 0.35, sd =0,85). This indicates that most parcels within built-up areas have a higher quality or have a registered area derived directly from the parcel geometry. Comparing Verblijfsobjecten (M = 0.11, sd = 0.26) and Woonobjecten (M = 0.10, sd = 0.22) shows that the mean M-value stays the same for Verblijfsobjecten and even improves a bit for Woonobjecten. This indicates that parcels classified as Woonobjecten have a better corresponding registered area, even though not all parcels are inside the built-up contours. The other way around is seen for parcels in the Natura2000 areas with a mean (m = 0.77, sd = 1.75), indicating that parcels inside Natura2000 areas have a significantly higher difference in area.

This difference can also be seen when inspecting the OD and significance maps of the Netherlands, Utrecht and Nieuwkoop. It shows the clustering of parcels with a high M-value for parcels located inside nature areas, along the river and the coast and inner cities to a lesser extent. It is also possible to see low-low clusters on the map, which mainly can be identified as agricultural land readjustment, relatively new neighbourhoods, and certain villages. When comparing the mean OD values of sections, it is possible to see a pattern where the OD value decreases the further away you go. This is also visible in Utrecht, where the neighbourhood Leidsche Rijn has a low M-value, while the houses in the Meern have a relatively high M-value. This can indicate that the quality of the parcel geometry and size improves the newer the neighbourhood gets.

Local Moran's I for the whole of the Netherlands (I = 0.193) shows that parcel M-values are predominantly random from the mean, but there is a weak clustering of similar values. The High-low relationship only applies to 28925 parcels, meaning that it is rare for a parcel with a high m value to be surrounded by low m value parcels. This would make sense because when the surrounding parcels are of high quality, their shared boundary should also be of high quality. Assuming a mistake or a non-correct registered parcel size is possible when this is not the case. The other way around happens to be 213804 parcels.

The result of the hypothesis; "*Rural areas differ more than the built-up areas between the registered and calculated surface area than the built-up areas*". It shows that there's a significant difference between parcels within built-up areas (M = 0.10, SD = 0.22) and those inside rural areas (M = 0.35, SD = 0.85). It indicates that the surface area of parcels in built-up areas corresponds better to the registered parcel area. This would confirm the hypothesis that rural areas differ more in the difference between the registered and surface area of parcels. It also corresponds to the higher quality requirements of built-up areas (Van Den Heuvel et al., 2022).

From the results, it is possible to conclude that a selection can be made of parcel types and identify relations between their M-value. Furthermore, the combination of the OD map and the significance map shows clear spatial patterns and that parcels' spatial distribution is primarily random, but it tends towards clustering.

5.1.3. Sub-question 3

The third sub-question of this research is: *What cartographic visualization should be used to visualise changes in WOZ, area, and clustering of the KKN?*

Correct visualisation is necessary to implement the new Cadastral Map to identify the impacted parcels. This means choosing the correct visualisation techniques to help the Kadaster identify parcels affected by the current and future Cadastral Map (Hanus et al., 2018; Kwinta & Gniadek, 2017). Correct visualization techniques are essential when analyzing the parcels of the Netherlands because, for example, large-scale visualization makes it challenging to identify impacted parcels (Kraak & Ormeling, 2020). The research also shows that parcels of a smaller size are not easily visible, while the larger parcels are visually dominant. It is possible to draw wrong conclusions from the data, giving the illusion that larger parcels are more impacted. This means the visualisation needs to use different scale levels and aggregations to analyse the potential impact properly.

Data aggregation helps to identify and get an overview of municipalities and sections affected significantly. The aggregation on municipalities shows the impact based on the classification of area and OD value. However, the size of the parcels makes it so that the values are averaged out. Creating a situation where the most common category becomes ODC. Using sections, however, gives a better image. Identifying outliers in the data is now possible, showing that certain municipalities are averaged between high and low M-value sections. Sections are also a better visualisation technique because land readjustment policies show that they use sections inset. From this, we can conclude that aggregated municipalities can be used to identify outliers and municipality statistics, like the minimum and maximum of the parcel surface area. The aggregation, however, means that detail is lost; it is the difference between 85854 municipalities and 7703 sections.

The OD classification used is based on the classification system of the Kadaster, which works with colours based on the European energy label system. The OD visualization uses seven classes, which fit the maximum allowed values in a choropleth map (Kraak & Ormeling, 2020). The colours are easily identifiable as a quality measurement because they use a red to the green ramp. However, this colour system does not consider colour blindness and makes it possible for people to overestimate the error in area due to colour association and does not consider contrast (Brewer, 1994). A more neutral colour scheme could help better implement the OD system and the analysis of the problem. Furthermore, a light-to-dark progression scale of colours allows more easily detecting of the OD categories' sequential order. An alternative colour scheme is shown in Appendix 1.b.

On a small-scale level, the boundary of the parcels needs to be removed to ensure that the parcel's boundaries are not visually dominant. Area difference uses a similar system, but the chosen colours diverge. With the lowest values being the lightest and the largest being the darkest, the chosen colours are also based on colours that do not imply a difference between negative and positive values. This method allows for finding outliers in the data and correctly identifying affected areas, sections, and municipalities.

Another part of this research is finding clusters in the dataset using Local Moran's I. Visualizing the clusters allows for identifying areas that are outliers in the complete dataset. The high contrast within GeoDa allows for better identifying spatial relationships and helps to find parcels and regions using the OD map. Because visualization of the outliers can help determine which areas are the most and least affected (Hanus et al., 2018). This is also visible in this research, wherein areas can be identified due to combining the cluster map and the OD map.

The visualization shows that it can affect the OD values, area, and clustering. It allows for identifying spatial relations and shows which areas are more affected than others. It also shows that it is essential to include different scales.

5.1.4. Sub-question 4

The fourth sub-question of this research is: *In which way do different stakeholders differ in their willingness to accept cadastral changes?*

The willingness of the stakeholders for cadastral area changes is something which has not got much research. However, there has been research into the effects of land redistribution and consolidation efforts. Zhang et al. (2018) concludes that smaller farmers are more averse to land changes than farmers owning large parcels. They also conclude that smaller households should be prioritized in land change policies to lessen the effects of land reallocation. Lastly, the active participation of landowners within a project will smooth the land consolidation processes. Lisec et al. (2014) article mentions that good practices and participation are essential for land consolidation.

Land readjustment policies also need to use a systematic approach based on land policies. Land readjustment should usually use land value and different financial models in different urban areas. Furthermore, land or value base systems should be well-modelled along different stakeholders. This means that the parcel readjustment needs to be modelled around the type of parcel owner and the plot size (Yilmaz et al., 2015).

5.1.5. Sub-question 5

The fifth sub-question of this research is: *In what manner may the land values of the impacted cadastral parcels change because of the implementation of the KKN?*

The value of parcels will change with the implementation of the KKN, but the impact will differ between regions and forms of land use. According to the articles of Kara et al. (2019) and Kathmann & Kuijper (2018), the value of parcels is partly based on the area difference. It is one of the primary object characteristics for calculating the WOZ and is calculated differently for different regions and land-use types. This calculation can be based on a price change index of the region and the original land value.

Another aspect influencing the change in the ground-price value of parcels is the “afneemende meetwaarde” (decreasing added value). With a decreasing amount of added land value for parcels up to around 10.000m^2, at which point the added value of an extra meter is minimal in the Netherlands (Oosterveld, 2016). Each square meter has a lesser impact on the total valuation of the parcels (Belastingsamenwerking Oost-Brabant, 2021), which means that a change in area for smaller parcels is more significant than a change in area for larger parcels. As such, the manner of change in ground price will depend on the parcels' size, type, and region. Furthermore, it is possible to assume that the impact will be more significant for smaller parcels in areas of high value, like inner cities.

5.1.6. Main research question:

How will the implementation of Kadastrale Kaart Next (KKN) affect the area of different categories of parcels, WOZ value, in the Netherlands and how to visualize it?

With the sub-questions answered, it is possible to answer the main question of this research how to visualise and determine the impact of the KKN. This research shows that it is viable to visualise the 8 million parcels in the Netherlands and make it possible to find patterns in the data. This can be done using different visualisation techniques like; Bek's formula, univariate local Moran's I and visualisation of the area difference. It shows potential areas impacted, like rural and nature areas or less impacted, like new urban areas and land reallotment by the implementation of the KKN. Furthermore, parcel variables can be used to identify the impact on different parcels.

The result shows that the mean parcel has a mean value of m = 0.16, meaning that they are within the ODC category of the Kadaster, which is above the current quality limit of the data show less impact for parcels in built-up areas versus rural areas. Furthermore, parcels with the variable Woonobjecten have an even lower M-value, implying that parcels containing a house are probably less affected by the implementation of the KKN. The parcels located in Natura2000 areas have a mean M-value of 0.76, meaning that those areas have a large difference in area. The difference in area is also visible in the Netherlands, where the calculated surface area is 0.76% larger than the registered size. This difference is not evenly distributed in the Netherlands and can differ broadly between sections and municipalities. The results show that the registered size needs to be changed for many parcels in the Netherlands.

This research also identifies a potential difference in impact for different stakeholders and the land value based on literature. Large landowners are, for example, more willing to corrections land area than small landowners. The literature also shows that parcel value in the Netherlands is mainly based on the original land value, updated based on an index. Furthermore, the impact on the value of parcels depends on the location and the parcel type. Lastly, the value of a square meter decreases the larger the parcel is and caps around 10000 m², which means that changes in the registered area have relatively less impact on larger parcels and their owners. While smaller parcels are most likely more impacted by the Cadastral Map.

However, it is impossible to directly conclude the impact of area through the KKN pilot itself. The observations in the pilot dataset are too small to draw a representative conclusion about the impact. For example, from the limited data, it is not possible to conclude that there is a significant relation between the parcel's current and the future M-values of parcels. However, a few observations can be made; firstly, the parcel with a downward shift in their vertices had a low M-value. Secondly, the parcel's boundary surrounded with parcels of ODA class did have a small difference in M-value. Furthermore, all the parcels had a calculated surface area change, and not every parcel got close to the registered area.

The research results show that it is possible to visualise the data and test for the impact of the difference between the registered and the calculated surface area. However, it is impossible to precisely know the impact of the new Cadastral Map before a larger pilot dataset is implemented. This means that only parcels that already exceed the current quality limit set by the Kadaster can be reasonably expected to change. Furthermore, areas with a low-low relation might have a minor change. Lastly, houses and parcels in built-up areas are potentially significantly less impacted by the new Cadastral Map. However, the techniques used in this research can be used for selecting areas to implement the new Cadastral Map.

6. Conclusion

This research shows that it is possible to analyse the impact of the new Cadastral Map on the calculated and the registered surface area of parcels. The research also shows that the area difference of parcels in built-up areas is significantly larger than in rural areas. The difference is even more pronounced for parcels with a Woonobject inside. In comparison, parcels inside Natura2000 areas have a significantly higher mean M-value than parcels outside Natura2000 areas. The research also shows that governmental parcels have larger discrepancies in area than non-governmental parcels.

The discrepancy indicates that parcels within Natura2000 and governmental parcels are potentially more susceptible to area changes, which can mean that the registered parcel area needs to be changed more often. However, the mean area difference of all parcels falls within the ODC category, which is below the current quality requirement of the Kadaster. In short, it shows that it is possible to identify the current parcel area difference for different categories, which can be extended with other parcel variables.

The research also shows spatial patterns present in the current Cadastral Map. The univariate Local Moran's I show that most parcels are spatial random but edge towards a positive spatial autocorrelation. The local univariate Moran's I show that only a few parcels have a High: low or a Low: high spatial relation, indicating that only a small part has a negative spatial autocorrelation. The resulting cluster map also shows the clustering of parcels with high spatial autocorrelation in surface area, an example of these is the following: land reallotment, new-urban areas, villages, and regions like the Flevopolder. At the same time, other parcels have high area differences: inside nature areas, rivers, and old city centres.

This research also shows that it is possible to visualise the area difference on different scales and aggregations. The proposed system of seven classes by the Kadaster allows for identifying potential outlying parcels, regions, municipalities, and sections on the Cadastral Map. Furthermore, it shows that visualisation can be used to analyse the relative and the absolute change in surface area. However, the proposed colour system by the Kadaster can potentially be improved with a multi-hue that is colour-blind friendly and uses a light-to-darkness progression.

The first hypothesis, "The registered area of the Netherlands is smaller than the actual calculated surface area", was confirmed and showed a 0.078% difference between the current cadastral map's registered and calculated surface area. This indicates that the total registered area does not conform to the total surface area of the parcels. This can be due to factors due to historical influences from the introduction of the Dutch cadastral system. The discrepancies can also be from measurement and writing errors. The discrepancy, however, means that in the KKN, registered and the calculated surface area of parcels will change.

The second hypothesis: "*The registered area of the Netherlands is smaller than the actual calculated surface area*". It was also confirmed that parcels within built-up areas had a lower mean M-value than rural parcels, indicating that the mean quality of parcels is better in built-up areas. The mean M-values are even lower than the ODE category, indicating that most parcels in built-up areas fall within the ODB category, corresponding to the quality limit set by the Dutch Kadaster of $5\sqrt{a}$ for built-up parcels.

The results from the hypothesis: “*Changes in a parcel's surface area likely mean that another surrounding parcel's surface area changes opposite to compensate for the change in the surface area.”*. Indicates that parcels in the Netherlands do not exhibit a clustering pattern of either positive or negative change in the difference between the registered and calculated surface area of parcels. These results imply that when there is a difference in the area of a particular parcel, the area of a neighbouring parcel is adjusted in the opposite direction. In other words, the observed changes in the area of a parcel lead to a surface adjustment among neighbouring parcels. It is, however, not known in the current research how large this adjustment is.

Lastly, this research looked at the Pilot of the KKN to analyse the potential impact. The result shows no significant relationship between the parcels' original M-values versus the M-value change. Furthermore, it did not explain the variance of the data. The limited number of parcels inside the pilot can explain this. The pilot did show a pattern of parcels with low shifts in vertices and surrounded parcels with low m values to change relatively. Using the current pilot data to predict the parcel area changes is not feasible. Combining it with the vertices' accuracy might give a better result, or the current model may be fit for purposes when tested using a larger pilot dataset.

However, this study encountered several limitations. Firstly, the unavailability of data from the earlier Cadastral Map restricted the analysis of historical changes and vertices quality. Additionally, the direct utilization of WOZ data in the research was not feasible. Due to constraints in time, data availability, and scope, the investigation could not assess the impact of the KKN program on parcel vertices. Moreover, this research does not provide definitive predictions regarding the outcomes of the KKN program. Furthermore, further examinations are required in areas exhibiting distinct spatial patterns, such as those with high or low spatial correlation or spatially random distributions.

Likewise, this research underscores the necessity for future studies to explore the effects of the KKN program on a broader scale, encompassing a larger number of parcels. Additionally, future investigations could expand the range of selected variables. An analysis of the applicability of the OD system of the Kadaster on the future KKN project could be explored. Furthermore, it would be valuable to determine if increased observations yield better results and allow for predicting the impact of the KKN project. However, the current methodology can still be applied to identify existing and future parcels within the Cadastral Map that display significant disparities in area.

Future research endeavours can focus on improving the following areas:

- Use web-map visualization techniques to provide a more comprehensive and user-friendly way to display the data.
- Expanding the scope of the research by analysing more areas from the KKN project.
- Comparing the applied methodology with alternative approaches to assess the accuracy and efficiency of different techniques.
- Exploring the impact of parcel vertex shifts and investigating their implications within the research context.

Addressing these areas of improvement will contribute to advancing the understanding and application of the research findings in the field of cadastral mapping and provide valuable insights for future studies.

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8. Appendix

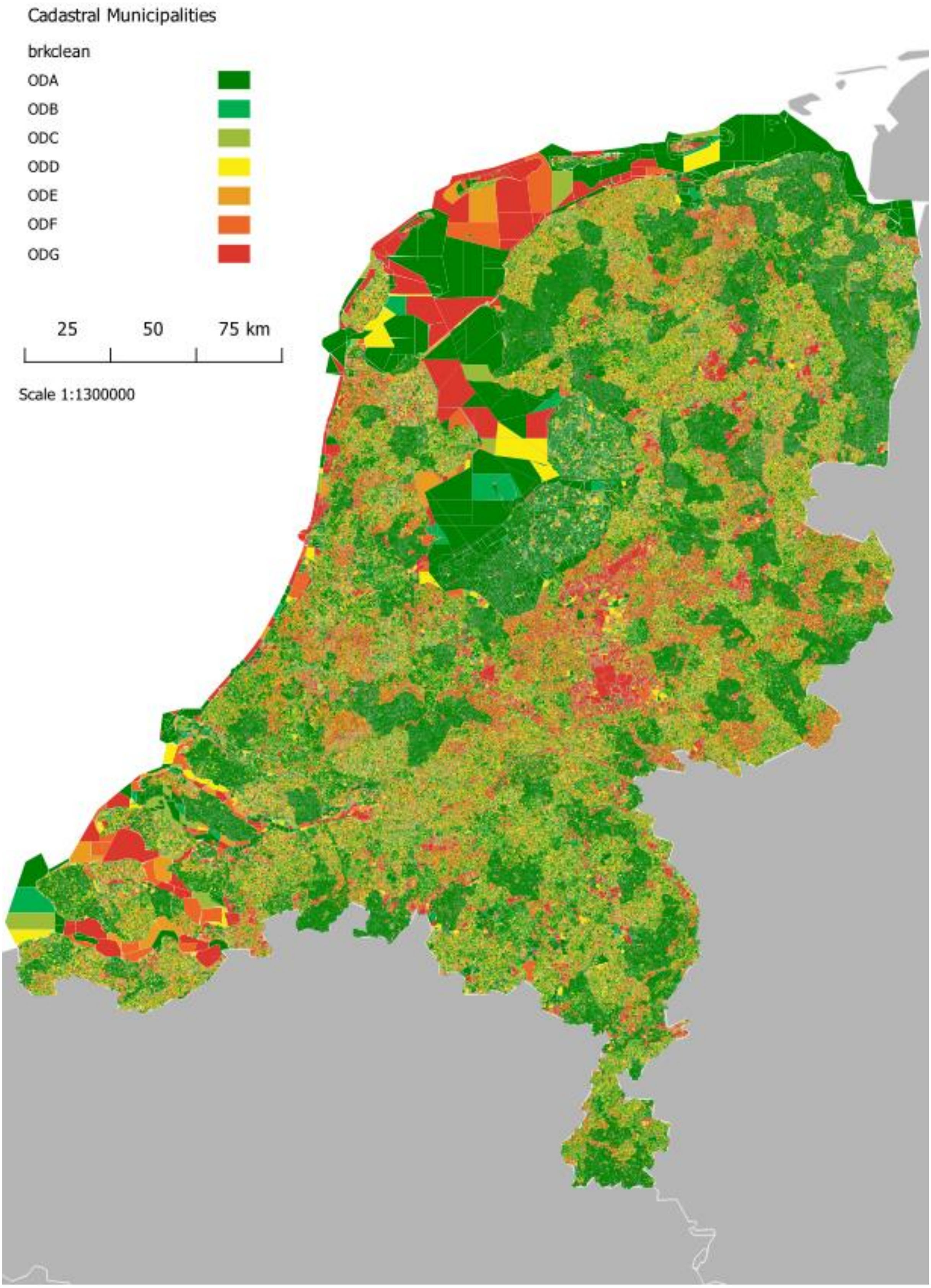

Figure A.1a OD map Netherlands

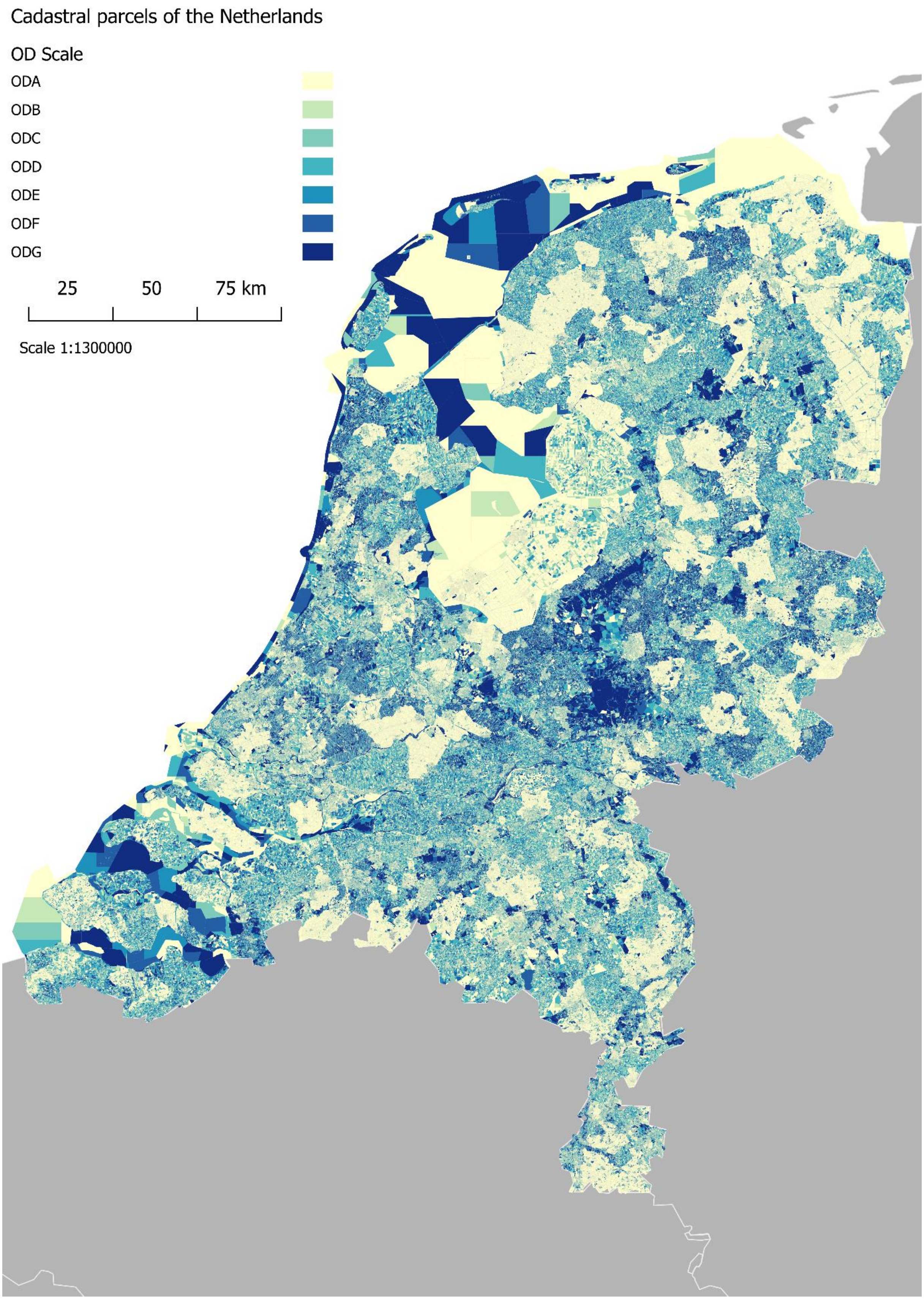

Figure A.1b OD map Netherlands with alternative colour scale

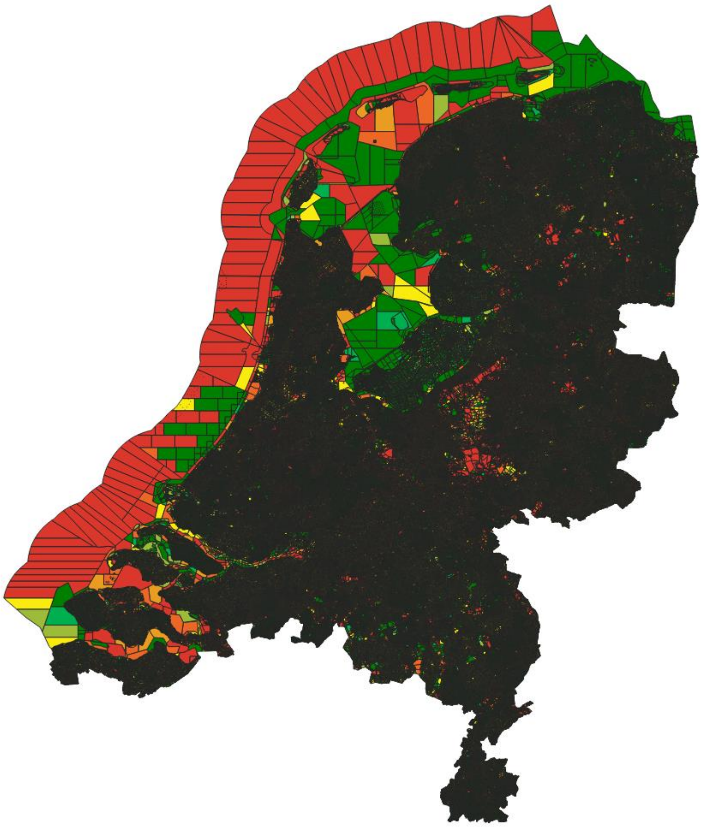

Figure A.1C OD map Netherlands with borders coloured in

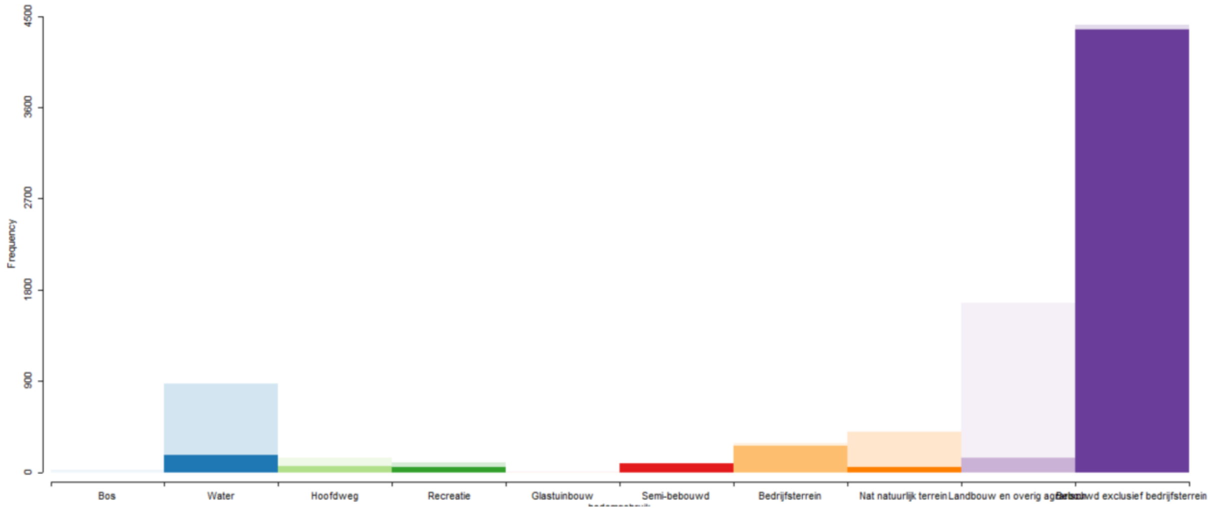

Figure A.2 BBG landtypes Nieuwkoop

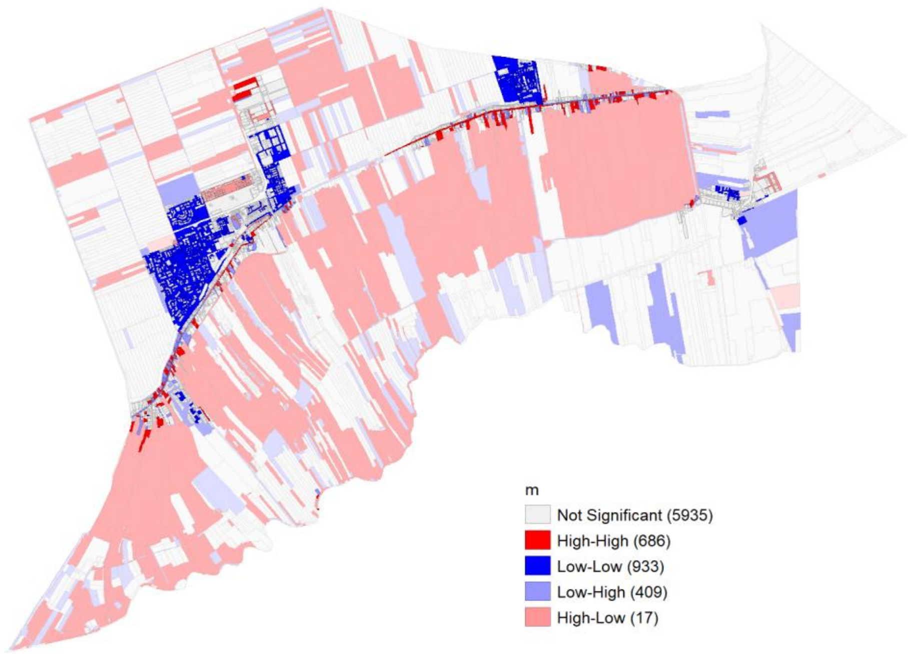

Figure A.3 Moran's I map Nieuwkoop

Figure A.4 Significance map Nieuwkoop