Urbanization trends in North- and South-Brabant between 2000 and 2015 using the Global Human Settlement Layer dataset

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Picture taken of the city of Breda, Source: Zodiac de musical (z.j.)

Abstract

With an increase of the global urban population, there has been an increased need to analyze urban trends and their future consequences. This has been done many times by looking at changes in total buildup areas. That does, however, not show the whole picture: Urban population can also increase through densification in already buildup areas. This research, therefore, tried to analyze densification through urban population trends. This has been done for the six largest cities in the former region Brabant, which is currently split into North-Brabant and South-Brabant, that are in two different countries with very different urban planning policies. To analyze these areas, the Global Human Settlement Layer dataset has been used to compare the population distribution between the years 2000 and 2015. Through comparison, it was found that there was only city center densification in the cities Brussels and Antwerp. These findings do, however, suggest that the GHSL data might not be accurate enough to be useful for these city-scale analyses. Therefore, a combination of the GHSL data with other datasets is needed to be able to analyze future city population trends.

Keywords: Global Human Settlement Layer, agglomeration, urbanization, urban density gradients

Inhoud

1. Introduction

Since 1800 the world population has had an exponential population growth from 1 billion to almost 8 billion in 2022 (Roser, et al, 2013). This total population is expected to keep increasing until at least 2080 (The World Bank, z.j.). This trend goes hand in hand with an increase in the amount of people that live in urban areas. A consequence of this is that there is not enough urban area for all people to live in. Therefore, most cities experience expansion of urban area with an increase in urban population cities (Seto, et al, 2012).

The expansion of urban areas are is often described with the term 'urban sprawl'. This is the rapid expansion of cities and towns with geographic location and is often characterized by a relatively low density (Rafferty, J. P., 2021). A region with 10% urban land is less sprawled than one with 20% urban land if the total population is the same, and a region shaped as a circle is less sprawled than a territory with smaller separated circles (Buitelaar and Leinfelder, 2020).

Urban areas can, however, also grow through densification. This is the process in which urban areas get an increase in population density (Pelczynski, and Tomkowicz, 2019). This process occurs in many places, especially in urban areas that are growing fast, have a change in demography, economic pressure and infrastructure projects (Pelczynski, and Tomkowicz, 2019). A region becomes more dense when more people live in the same area from one year to another (Teller, 2021).

Expansion of urban area is one of the most irreversible impacts of humans on the environment because of the conversion of green land or agricultural land to build-up area (Seto et al, 2011). Henning et al. (2016) has produced an extensive review of the effect of urban expansion based on previous literature on this topic. In this report, there are more than 60 different negative effects mentioned such as effects on the landscape, flora and fauna but also on hygiene and other health problems.

These problems occur in urban areas all over the world. Urban densification, instead of expansion, does have less of these negative impacts. It is therefore important to be able to analyze and monitor urban areas and trends of urbanization, to be able to reduce the impact on the environment.

Urban trends can be analyzed by looking at the urban population density gradient of an urban area. This is a gradient that shows the spatial variation of density over an area and is most often used for monocentric urban areas. By looking at the gradient, it is possible to determine the structure of a city as well as how sprawled the city is. When the city has a relatively high urban sprawl, the population density gradient is relatively flat, while a relatively steep gradient belongs to low urban sprawl.

In this research, a small study area has been chosen to analyze urban sprawl and the development of this. This area consists of the Dutch province North-Brabant and three provinces in Flanders (Belgium) that used to be part of Brabant until the nineteenth century. This densely populated area will be analyzed by looking at the six largest cities over a time period between 2000 and 2015. This will be done to be able to look if there are significant differences between the Dutch cities and the Belgian cities. This might be the case, since both countries have had a very different urban planning structure (Buitelaar and Leinfelder, 2020).

Therefore, this paper tries to make a comparison between North-Brabant and South-Brabant between 2000 and 2015 by using the Global Human Settlement Layers (GHSL). To do this, part of the research consists of a validation of the GHSL dataset by comparison with the Dutch central statistical dataset (Centraal Bureau voor de Statistiek).

The research question for this thesis is: *How do urbanization trends compare in cities in South-Brabant and North-Brabant between 2000 and 2015 when looking at changes in urban population density of six cities?*

The sub questions for this research question are the following:

-How do spatial planning traditions differ between the Netherlands and Belgium?
-How did the population density gradients develop in the past decades (especially between 2000 and 2015)?
-What are general trends of the six cities and do these differ between the cities and between the Netherlands and Belgium?
-How do the results of Tilburg, Breda and Eindhoven with the GHSL data compare to the results with CBS data?
-How does literature on population density trends compare to the results found in this research?

This paper is structured as follows: The first section will give some more insight into the study area and urban cityplanning in this area. This is done by using previous literature on both countries. The next section will give some information on the data that is used in this research. After that section, the research method will be described which will be followed by the results section and the discussion and conclusion.

2. Case study area

The study area of this research is based on the area 'Hertogdom Brabant' that existed between the Late Middle Ages and the nineteenth century (figure 1). Currently, this area is split into two different countries: the Netherlands and Belgium, and over four provinces: the Dutch province North-Brabant and the Belgian provinces Antwerpen, Vlaams Brabant and Waals Brabant. Even though this is a relatively small area, it is very densely populated (Worldometer, 2022) which makes it interesting for urban trend analyses.

Figure 1: Study area of this research, former 'Hertogdom Brabant'. Source: Canon van Nederland (z.j.)

To do this, the six largest cities in this region will be analyzed: Breda, Tilburg and Eindhoven in North-Brabant, and Brussels, Antwerp and Leuven in Flanders. All cities have been founded in the Middle Ages and have historic centers. The largest of the cities is Antwerp with a population of more than 500 000 inhabitants. The smallest city is Leuven with more than 100 000 inhabitants.

The city with the highest population, when looking at the whole agglomerated urban area is, however, Brussels. Figure 2 shows a map of the population density of Brussels and the surrounding areas. The city of Brussels only has about 185 000 inhabitants, while the whole agglomeration has more than 2 million inhabitants. Because many people in Brussels live in the neighboring areas, these areas will also be counted as the city population of Brussels in this research.

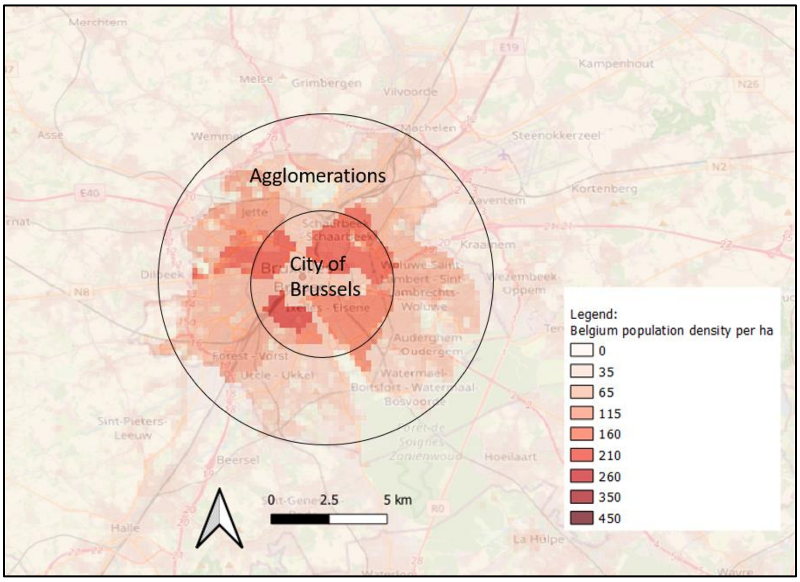


Figure 2: Population density of Brussels and the surrounding neighborhoods. The rings show the areas of the city of Brussels and the agglomerations of Brussels.

Urban planning in the Netherlands can be said to be relatively pro-concentration and polycentric (there are different citycenters and the urban sprawl is relatively low) (Claassens et al, 2020). The Flemish cities used to have a more pro-dispersion regulation, but this has shifted to more pro-centric since the 1990s (Buitelaar and Leinfelder, 2020). These trends can also be observed when looking at urban sprawl: Flanders has more dispersion, non-systematic and overall more urban area than the Netherlands. The Flemish regulation was done through a system of permits that was based on 'zones' and a few generic building laws (Buitelaar and Leinfelder, 2020).

According to the Dutch central government (Rijksoverheid, Ruimtelijke Ordening, z.j.), the Netherlands has had many different policies for urban planning post-WWII. The first policy was of national buffer zones (Rijksbufferzones) that were zones that were to remain green or agricultural areas between the major cities in the west of the country (the Randstad). These zones were safeguarded with local land-use plans, the so called 'bestemmingsplannen'. These were meant to control urban sprawl and created the current pro-centric city structures. Another policy that has had major impact on the current city structure was the New-Town policy (groeikernenbeleid) in which areas were pointed out where urban area was allowed to grow. More centers arose because of this: it created the polycentric character of urban areas in the Netherlands.

Recently, there has however been a stop to these Dutch urban planning policies. The Dutch government on landuse planning became more decentralized. In the Netherlands, it has been found that cities got an even steeper gradient between 2000 and 2017 (Broitman and Koomen, 2019). This could be partly explained because of the presence of historic centers and the extra services of cities. There are therefore more explaining factors for urban sprawl patterns than just governmental planning.

There has, however, been a change in Flemish urban planning. Since 2010, the government has had new ambitions to reduce daily growth of urbanized area. This is known as the 'concrete stop' (betonstop). This has, however, not been formally approved and the actual urbanization has kept increasing. Institutions are therefore still supporting the pro-dispersion discourse that already existed in Flanders.

Therefore, it can be hypothesized that until the end of the 20th century, the urban density gradient was more steep in cities in the Netherlands than in Belgium. Whether this changed in Flanders will be researched in this paper.

3. Data

The dataset that is used in this research is the Global Human Settlement Layer (GHSL) dataset. This is a global raster dataset with a resolution of 250 x 250 meters. The coordinate system for this is Mollweide.

This data provides detailed information on the growth of buildings and populations over the last 40 years (1975-2015). This data is mainly based on two quantitative factors: the spatial distribution of buildup structures and the spatial distribution of resident people.

This spatial data was found through a combination of global satellite image data, already existing global census data and geographic information sources obtained by crowd and volunteering sources (Florczyk, et al, 2019).

In this research, the population spatial distribution will be used. This is the GHS-POP (2000 and 2015) layer that shows the population distribution through the number of people per gridcell. Residential population estimates were provided by CIESIN Gridded Population of the World, version 4.10 (GPWv4.10) at a polygon level and were further analyzed and updated, which was partly based on the GHSL BUILT-layer (Florczyk, et al, 2019).

The reason the population layer will be used in this research instead of the buildup area layer, is that the BUILT layer only shows per pixel if there is urban build up or not. This does not show the population density of an area and is therefore not very useful for this research.

The GHSL data has been found to be at least very useful for creating a global baseline in demographic analysis (Melchiorri, M et al, 2019). How useful it is for smaller scale analysis is not very sure however. A study on local rural-urban structures over a period of time in the state of Massachusetts (USA) tried to evaluate the accuracy of the GHSL database on small scale areas. There was an increase of accuracy in urban areas compared to rural areas and an general increase in accuracy over time. This was mainly caused by peri-urban densification processes in the study area. There also was an overestimation in more densely populated areas due to omission errors (Uhl and Leyk, 2022).

The GHSL dataset has also been validated for European countries and the United States. In a paper of Liu, F., et al (2020) it has been researched whether this data can be used for Asian countries. What was found is that the intensities of pixels in GHSL are relatively higher than the pixels of the validation data. This means that the GHSL data tends to overestimate high density areas and underestimate low-density areas in Asia.

Whether this is relevant for the study area of this research is not sure, but it will be kept in mind when analyzing at the results. The accuracy of the GHSL dataset will therefore be analyzed by comparison to CBS data. This will be done for the three Dutch cities (Breda, Eindhoven and Tilburg). This will be done by comparing the urban density gradients of the three cities. This dataset is made by the Centraal Bureau voor de Statistiek (Statline CBS, 2000-2015). This is a highly detailed and accurate dataset for the Netherlands that shows the population based on postal codes. This data is vectordata with a resolution of 100 x 100 meters. The coordinate system was also chosen to be Mollweide so it can more easily be compared to the GHSL data.

4. Method

To analyze the trends in urbanization in the study area, a similar research method will be used as in the research of Broitman and Koomen (2019). The reason for this is that with only limited resources and time, this method has shown to give very accurate information on the spread of population within a city. What this method is, will be described in the next section.

The city centers of the six cities have been found by using the historic city centers. From these points, concentric rings of 500m are made. The maximum radius, and the maximum amount of rings, is calculated based on the city population. In the case of Brussels, the city population of Brussels and the neighboring areas will be used. By using this population, the same method as Lemoy and Caurso (2018) has been used. This formula for this method is:

$$Distance\ city = \frac{distance\ largest\ city}{\sqrt{\frac{population\ largest\ city}{population\ city}}} \qquad (1)$$

For the largest city, the city of Amsterdam has been chosen. The reason for this is that this is the largest city used in the research of Broitman and Koomen (2019), which makes it possible to compare the results of this study to their results for validation. Figure 3 shows the six cities in the study area and what these concentric rings look like.

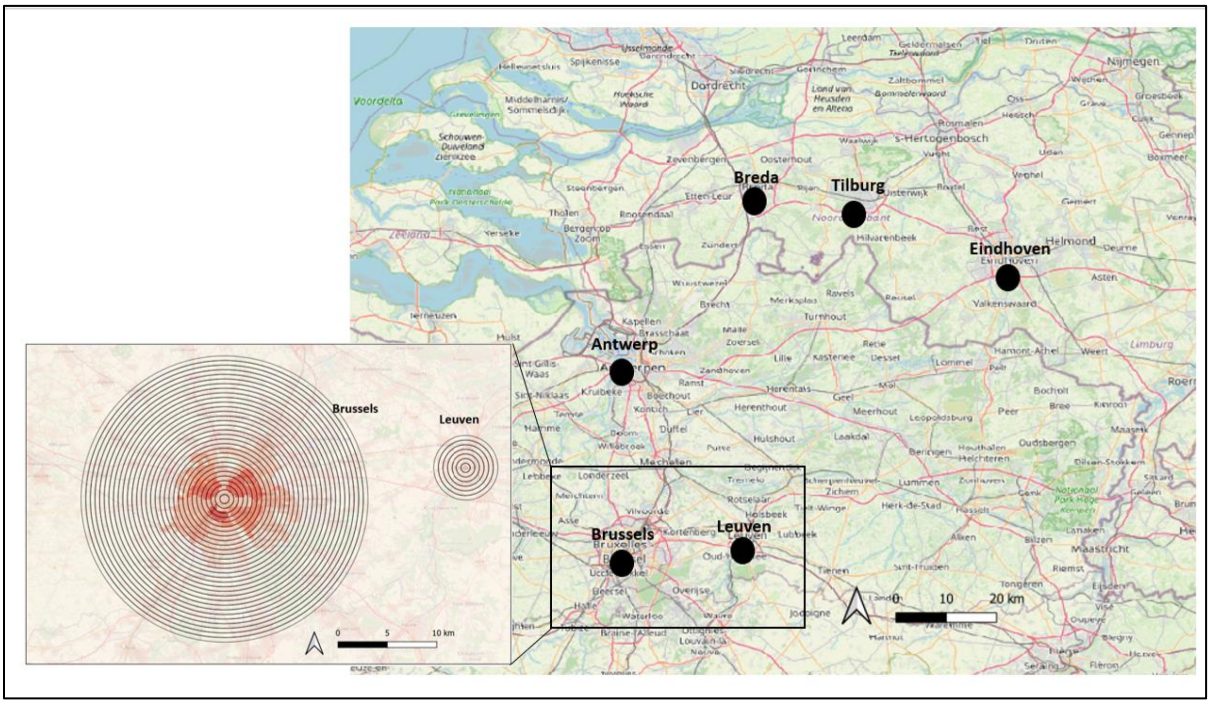


Figure 3: Location of the six cities in the study area and the concentric rings of Brussels and Leuven in detail.

After making these rings, it is possible to calculate the mean population within those rings. This will be through a GIS (QGIS 3.16 with GRASS).

The results will be checked by taking area with water into account, since this can give a bias. In the case large areas of water are present in one or more rings, it will create a bias of the results. Therefore, in that case the area of the water will not be included in the mean population of that ring and be given the value 'NULL'.

This will be done for the year 2000 and 2015 with the GHSL population dataset (res. 250m, Mollweide) in a QGIS 3.16 desktop.

After having mean population per ring for all six cities for the years 2000 and 2015, the next step is to regress the population density (inhabitants per ha) on distance from the center of the city (in steps of 500 meters). This will be done in excel, using the following basic exponential function:

$$Density = A * e^{b*d} \qquad (2)$$

Where ‘A’ and ‘b’ are coefficients that can be interpret in the analysis, and ‘d’ is the distance from the center.

This is the same formula used in other prior research (Broitman and Koomen, 2019; Ottensmann, 2016).

The coefficients and the R2 values will be summarized and interpret by comparison between the cities and between the years 2000 and 2015.

The same process will also be done with CBS data of 2000 and 2015 (Centraal Bureau voor de Statistiek, 2022) for the three Dutch cities. The reason for this is that this is a very precise and accurate dataset, which makes it useful for a comparison with the results from the GHSL data.

To compare the regions North-Brabant and South-Brabant with each other, not only the cities will be compared, but also an aggregate of the three cities per region. This is done by calculating the mean of the difference in population (between 2000-2015) per concentric city ring for the three cities in each region and comparing these graphically by using a scatterplot. This method is used mostly to get a better picture of changes in urban population distribution in both areas.

5. Results

5.1 Concentric rings

At first the concentric rings have been formed for each city. The locations and the amount of rings per city can be seen in table 1. Since the max radius has been calculated by comparison of the city population with the population of Amsterdam (see formula 1 in the method section), the first row shows the population, max radius and amount of rings for Amsterdam. After that, this information on the six cities of this study area can be seen. There is a big difference among the populations of these cities. The city of Brussels has by far the highest population and therefore got the highest amount of city rings (31 in total). This city is followed by Antwerp. The city with the lowest population in this study area is Leuven.

Table 1: Total population and concentric rings of the six cities and Amsterdam in the study area.

Cities	Total population	Max radius (m)	Amount of rings (per 500m)
Amsterdam	*872680*	*10000*	*20*
Antwerp	529247	7788	16
Brussels	2065284	15384	31
Leuven	102275	3423	7
Breda	184403	4597	9
Eindhoven	234235	5181	10
Tilburg	219632	5017	10

5.2 Urban density gradients

After making the concentric rings, the urban density gradient has been calculated per city for the years 2000 and 2015. The coefficients of these gradients (see coefficients 'A' and 'b' of formula 2 in the method section) and the R2 are summarized in table x. This has been done per city for the year 2000 and 2015. The R2 is relatively high for the cities Leuven, Eindhoven and Tilburg. For the other three cities, the R2 is, however, still 0,65 or higher. This shows that the results have a relatively high explanatory power.

The urban density gradients of all cities have a negative slope, which shows that population density does indeed decrease with distance from the city center. This does, however, not imply that all cities are monocentric. This can be seen for Brussels in figure 2 (Section: Study area).

5.3 Dynamics of population between 2000 and 2015

The coefficients 'A' and 'b' in table 2 (see formula 2 in the methodology) show the urban density gradients per city for the years 2000 and 2015. The gradient becomes steeper between 2000 and 2015 for the cities of Brussels and Antwerp, while the gradient becomes less steep in the case of the other four cities. This is in strong contrast to the hypothesis that at least the Dutch cities will have a steepening of the urban density gradient between 2000 and 2015.

The research of Broitman and Koomen (2019) did show a steepening of the urban density gradient during that period. They concluded that in all Dutch cities that have been researched, there was a densification of the city cores. This includes the cities Breda, Eindhoven and Tilburg. Therefore, the results of this GHSL analysis will be further analyzed in the next section.

Table 2: Coefficients and R2 of the six cities in the study area.

	Population density 2000			*Population density 2015*		
City	**A**	**b**	**R2**	**A**	**b**	**R2**
Antwerp	38,2	-0,00011	0,88	37,4	-0,00011	0,71
Brussels	137,5	-0,00024	0,65	177,7	-0,00025	0,65
Leuven	46,2	-0,00040	0,90	47,8	-0,00037	0,90
Breda	60,5	-0,00039	0,77	59,0	-0,00035	0,78
Eindhoven	55,7	-0,00025	0,91	55,7	-0,00024	0,90
Tilburg	93,4	-0,00047	0,91	89,0	-0,00044	0,89

5.4 An in-depth look at Brussels and Antwerp

In this research, there were some slight changes in the analyses of the cities Brussels and Antwerp. Brussels has been analyzed by looking at the city of Brussels and the neighboring areas that form the agglomeration of Brussels. The reason for this was that this would give a more accurate picture of the city population (Spaan et al, 2019). The city of Antwerp has been researched by only taking areas without water into account since areas with water could significantly impact the population density in the cityrings (Spaan et al, 2019). The next two sections show how the data of the city of Brussels and the whole agglomeration of Brussels compare, and how the population density of Antwerp with water areas compare to the density without water areas.

Brussels

Brussels has been researched a bit differently compared to the other five cities because the analysis also took neighboring areas into account. If this was the right decision has been analyzed in this section.

A comparison between the city of Brussels and the whole agglomeration are a of Brussels can be seen in figure 4. These graphs show the urban density of Brussels (a) and the urban density in case only the city population of Brussels has been taken into account (b). This graph shows that when looking at the whole picture (b), the city population density decreases with distance from the center. But, the first two rings, the center of Brussels, have a relatively low population density. A low density in the city cores can be seen in many cities worldwide and can be explained by more affordable living, while still having the advantages of living close to a citycenter (Thomas et al, 2015).

For this research, the whole agglomerated area should, however be researched, to be able to give a better picture of the city population behavior of Brussels.

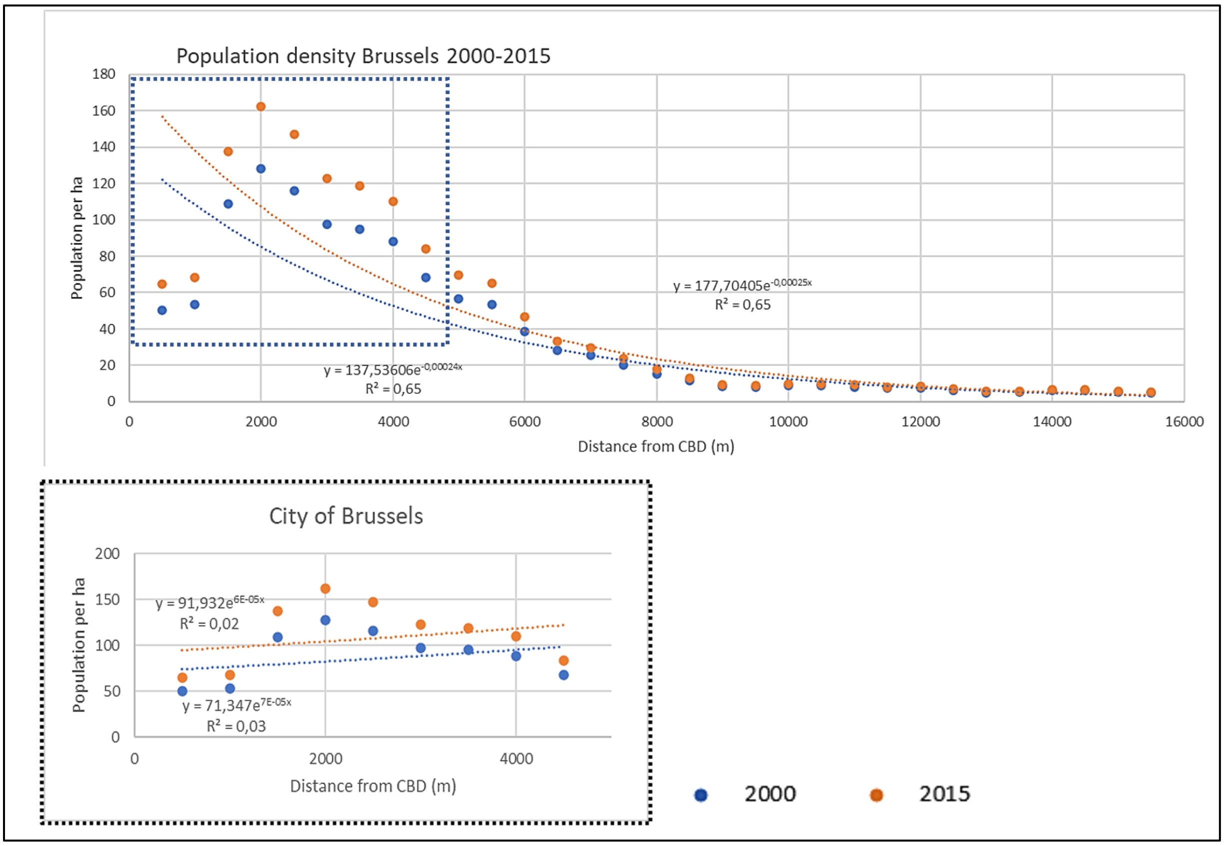


Figure 4: Population density of Brussels over distance (m). The upper graph (a) shows the population graph when taking the whole agglomeration into account, (b) shows the population graph when only the first nine rings are being researched.

Antwerp

The city of Antwerp has been researched by removing large areas of water and give those the value ‘NULL’. The reason for this is that it is not possible to live in those areas and that this gives a more complete results on the population distribution. In the other five cities, the areas with water are not large enough to make a significant difference in the population distribution gradient. Table 2 shows the coefficients and the R2 of Antwerp when that water pixels have been converted into the ‘NULL’ value (Without waterpixels) and without this conversion (With waterpixels).

The coefficients show that Antwerp has a higher average density per hectare if the areas with water are not being counted in the analysis. This was very much expected since the water areas are uninhabited. The density gradient is a bit steeper in case water area is not being counted in the analysis.

By removing the large areas of water, the data does, become a bit more regular. This is shown by the increase in R2. This shows that the local differences between the population of Antwerp are partly due to water area. By looking more precisely to the population distribution graph of Antwerp (appendix 2), it can be seen that there is a slight increase in population density in ring 3 through 7 when removing large water areas.

Table 2: Comparison of coefficients (A and b) and the R2 Antwerp with pixels of water and without.

Antwerp	2000		2015	
Coefficients	*Without waterpixels*	*With waterpixels*	*Without waterpixels*	*With waterpixels*
A	38,2	33,5	37,4	43,6
b	-0,00011	-0,00012	-0,00011	-0,00011
R2	0,88	0,71	0,71	0,90

5.5 Comparison between GHSL data and CBS data

Since the results of the Dutch cities behaved different than expected, these results have been compared to the CBS dataset. Figure 5 shows how the GHSL data compares to CBS data for the years 2000 and 2015 for the cities of Breda, Eindhoven and Tilburg. What immediately stands out is that the CBS data shows a much steeper slope of the density gradient for all three cities. The results of the CBS data also show a steepening of the density gradient for all three cities. This is in contrast to the results with the GHSL data. The total population also seems to be higher with the CBS data, compared to the GHSL data, especially in the more populated areas (towards the center). Therefore it seems as if the GHSL data underestimates the population density of the higher populated areas for these three cities. This might also explain why there is no steepening of the gradients with the GHSL data.

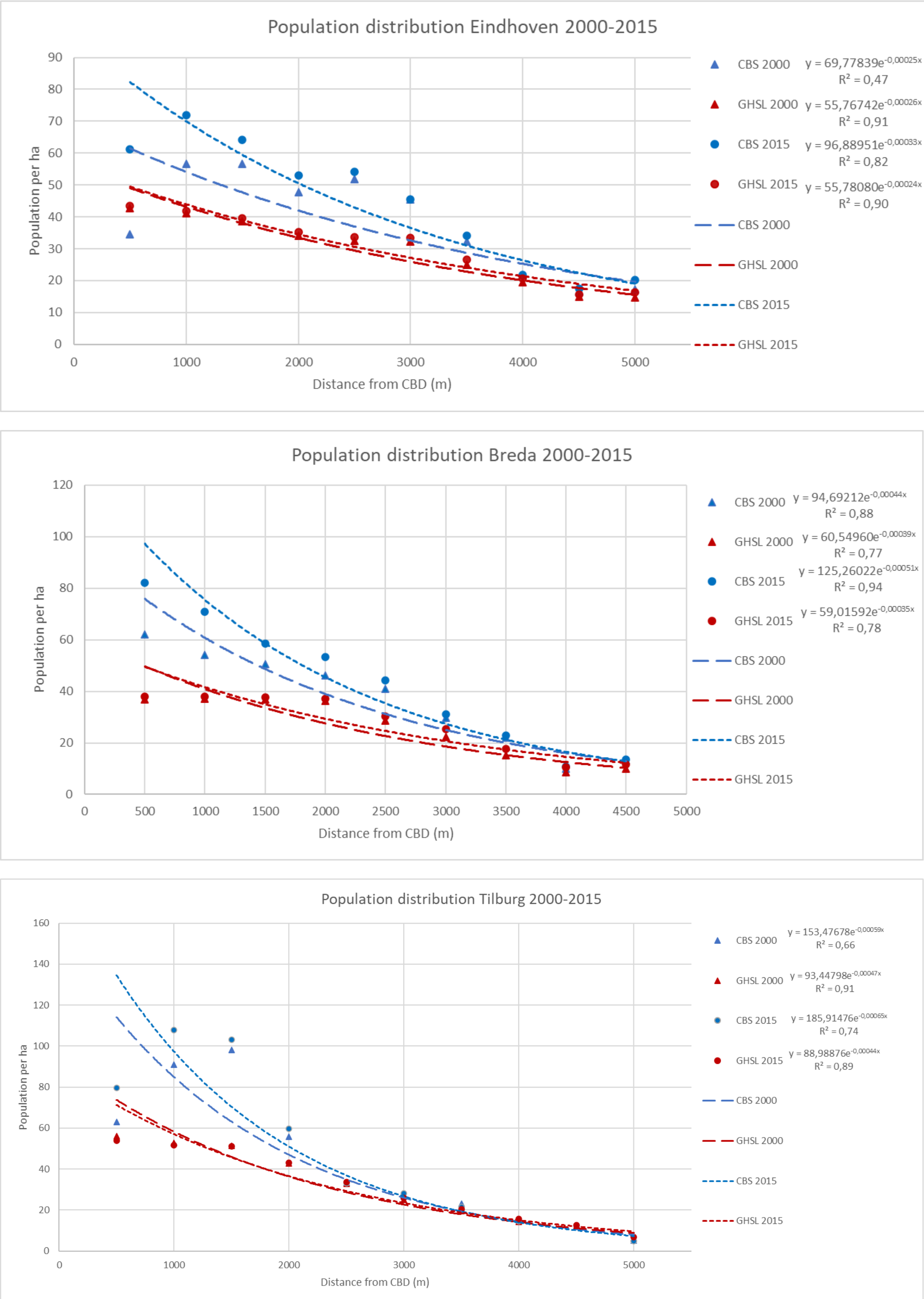
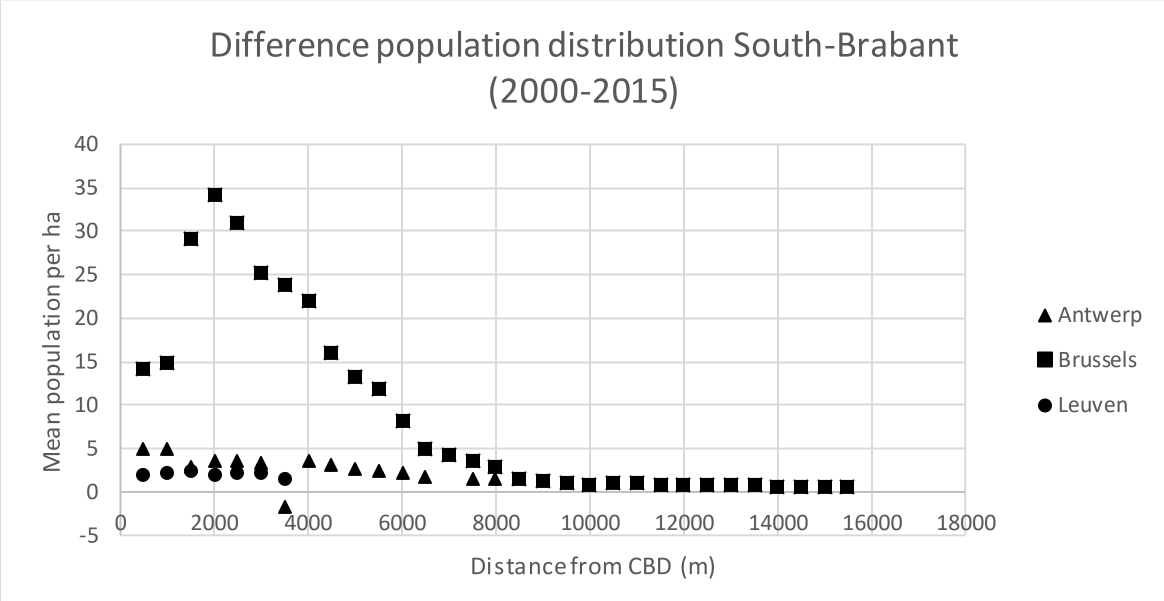


Figure 5: Comparison of population distribution between 2000 and 2015 using CBS data and GHSL data for Eindhoven, Breda and Tilburg. The formulas with the coefficients (A and b) can be found in the legend.

5.6 Comparison between the two countries

By looking at the coefficients in table 2, it can be said that the two largest cities in Flanders, Brussels and Antwerp, have gotten a steeper urban density gradient between 2000 and 2015. The gradient became less steep in Leuven. For the cities in North-Brabant, the urban density gradients became slightly flatter. This is in contrast to the results of these cities with the CBS data, where all three cities (Breda, Eindhoven and Tilburg) show a clear steepening of the density gradients between 2000 and 2015. Figure 6 shows the change in population distribution between 2000 and 2015 for both South-Brabant and North-Brabant. This gives an aggregated picture of both regions. For North-Brabant, this is also done with the CBS data (figure 7) to show that there might be similar trends between North and South-Brabant, even though the GHSL data shows major differences between the regions.



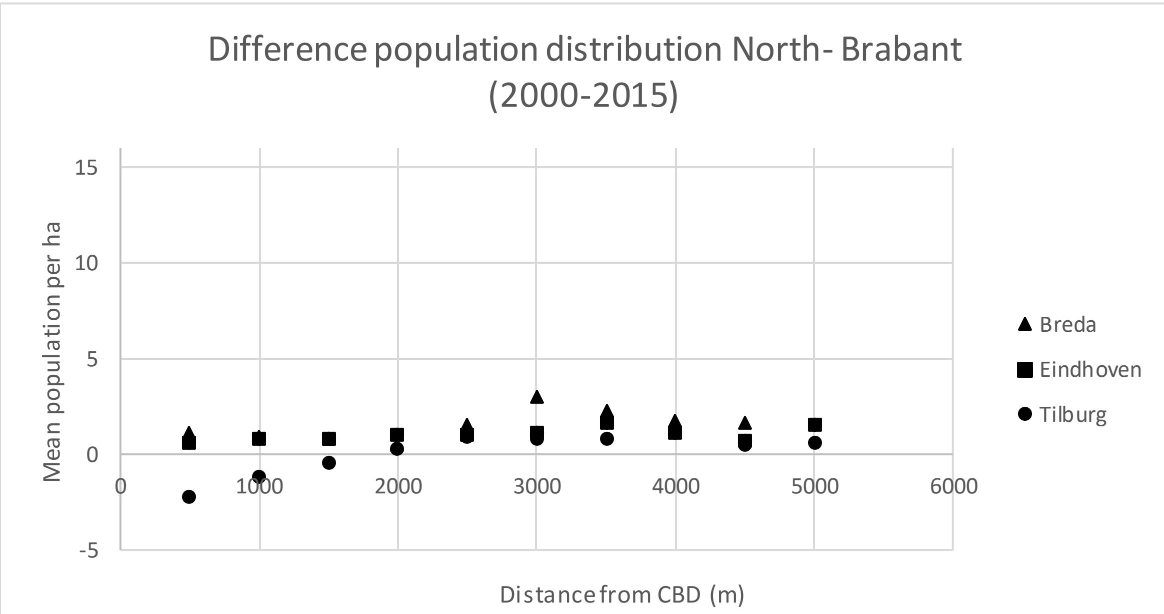


Figure 6: Aggregated difference population distribution South-Brabant and North-Brabant between 2000 and 2015. This was done by aggregation of three cities in both areas (Brussels, Antwerp and Leuven and Breda, Eindhoven and Tilburg).

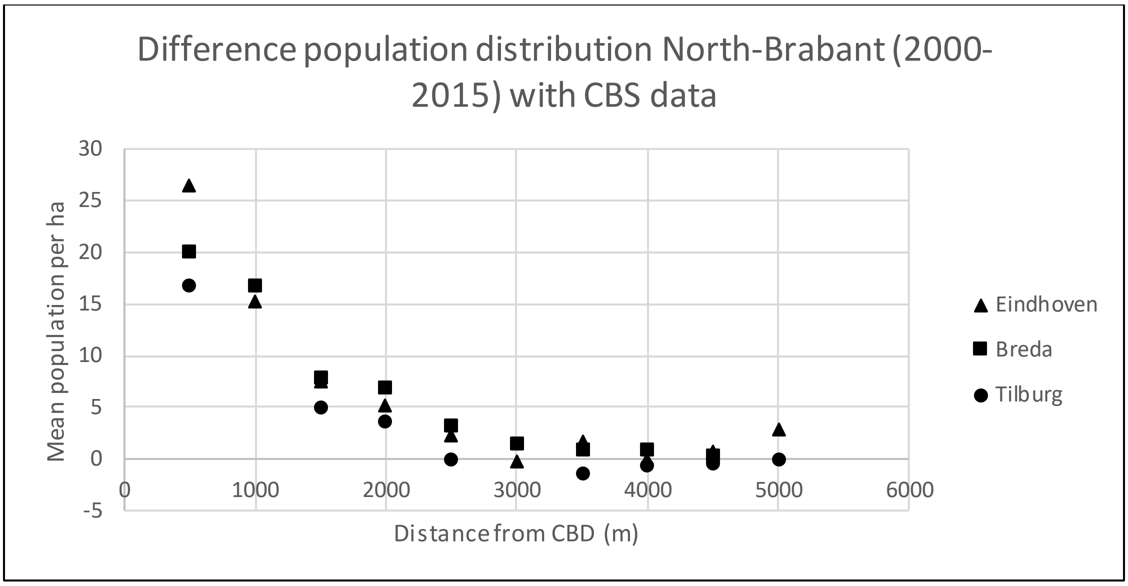


Figure 7: Aggregated population difference in North-Brabant when the CBS data is used instead of GHSL data.

6. Discussion

This paper has compared the dynamics in the urban density of the three largest cities in North-Brabant (Breda, Eindhoven and Tilburg) and the three largest cities in South-Brabant (Antwerp, Brussels and Leuven). This has been done by looking at the urban density gradients of these cities through the usage of the mean population densities of the cities per city ring. By doing this, the assumption has been made that, even though these cities are not completely monocentric. This was, however, still a valid assumption for this research, since all cities have the highest population density in the city center and a decrease in population density further away from the center.

Het GHSL data has been used to compare the population density gradients of the cities between 2000 and 2015. This analysis has shown that only Antwerp and Brussels have had a steepening of the gradient in this time period. This can be interpret as a densification of these citycenters. This shows that even with little practical changes in city planning policies, more people wanted to live in the city centers. This does however not say that there has been a decrease in suburbanization during this period. This did, namely not stop after 2000 (de Decker, 2011). The smallest city in this area, the city of Leuven did not show a change in slope between 2000 and 2015 with the GHSL data.

The GHLS data showed no steepening of the urban density gradient for the three Dutch cities. This is in strong contrast to the hypothesis, that there would be a steepening of the urban density gradient. That the GHSL data showed no such trend is therefore peculiar. Especially since the CBS data did show a steepening of the gradient.

An explanation to this difference is that there seems to be an underestimation of the population density with the GHSL data when compared to the CBS data. This might explain the absence of this trend. This raises some questions on the usefulness of the GHSL data for these kinds of analyses.

Multiple other researched also showed over- and underestimations of city populations in different areas. A research on the accuracy of the GHSL dataset for China (Liu et al, 2020), for example, has shown that the GHSL data seems to underestimate low-density areas and overestimate high-density areas, when using the BUILT-data. For two European countries, Portugal and Poland, the GHS-POP data underestimated densely populated regions and overestimated thinly populated regions (Calka and Bielecka, 2020).

By using satellite imagery to count the number of buildings and population statistics to estimate the population within a pixel, these inaccuracies could have occurred.

The GHSL dataset is, however, still relatively accurate in large urban areas when compared to four other datasets, GlobeLand30, GUF, GHSL, and UCL (only the UCL dataset was more accurate) (Yang, et al. 2019). That research showed that the best way to analyze areas is by using multiple products. That a combination of the GHSL dataset with other landuse maps gives very promising results, is also a conclusion of the research of Uhl et al (2021) on the combination of remote sensing maps of the GHSL dataset with georeferenced historical maps.

Since only two out of the six cities have a steepening of the gradient between 2000 and 2015 and these cities are by far the largest cities in this study area, it might also be the case that size of the analyzed area influences the accuracy of the results for the GHSL data. This should, however, be further researched.

7. Conclusion

A comparison of the three largest cities in North-Brabant and South-Brabant with the Global Human Settlement Layer dataset has shown that only the two largest cities in South-Brabant, Brussels and Antwerp, have had a steepening of the urban density gradient between the years 2000 and 2015. The other four cities did not show a major difference between the slopes during this period. These results are, however, in strong contrast to the general trends of cities in the Netherlands according to findings with data of the Centraal Bureau van de Statistiek (2000-2015). This data suggest a steepening of the slope in all three Dutch cities (Breda, Eindhoven and Tilburg).

This might be explained by a general trend in the GHSL data for European countries, that more densely populated areas seem to be underestimated, and less densely populated areas will be overestimated.

What these results have shown is that it is therefore very important to use other data sources and maps of a studyarea next to the GHSL data for comparison. This method will decrease the risk of over- and underestimations of urban populations which can negatively influence the overall results.

The results of the analysis of these six cities do, therefore, suggest that the GHSL dataset might not be very useful for a population analysis between two periods of time within a city. It might be that the GHSL dataset would be more useful for larger urban areas or urban areas in a different region, but this should be researched further.

By using the CBS data and previous literature on these six cities, this research found that the Dutch cities got an overall increase in population density and a steepening of the urban density gradient. This suggests a densification of the city centers. In Flanders, the cities Brussels and Antwerp did also show a steepening of the slope, even with the GHSL data.

In both North-Brabant and South-Brabant the gradients have steepened, while the planning policies have become less strict in the Netherlands than before 2000 and in Flanders, the policies have in practice not become more strict after 2000. This might suggest that there are other factors that influence city population trends than policies and might indicate that policies are not always very effective. This should, however be further researched.

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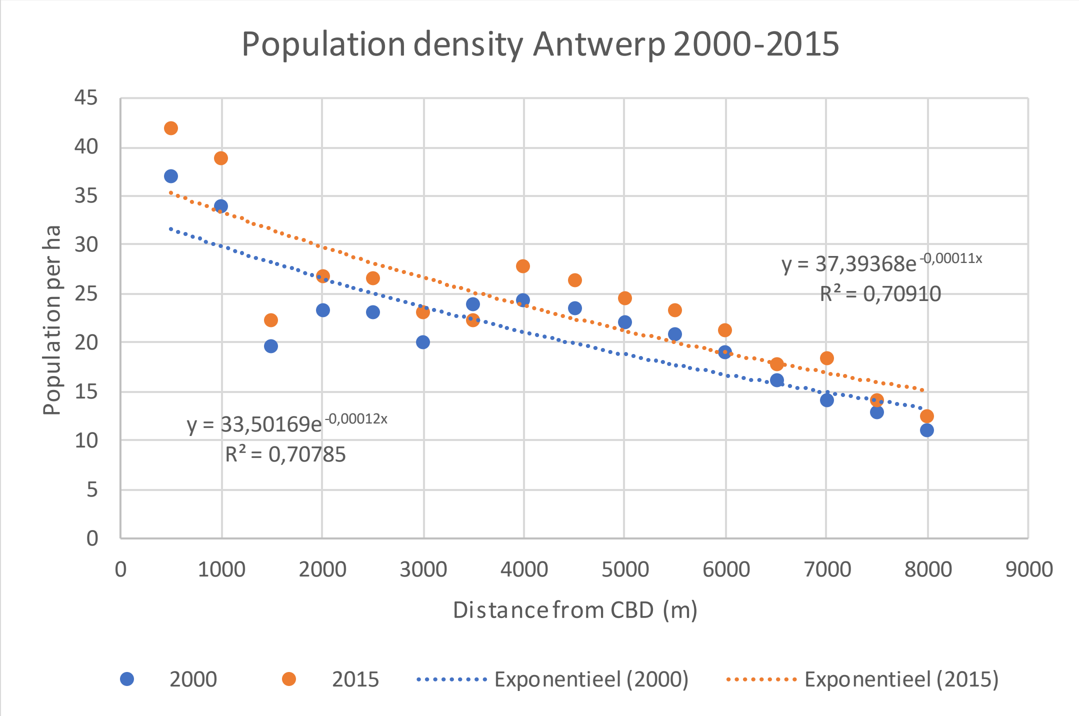
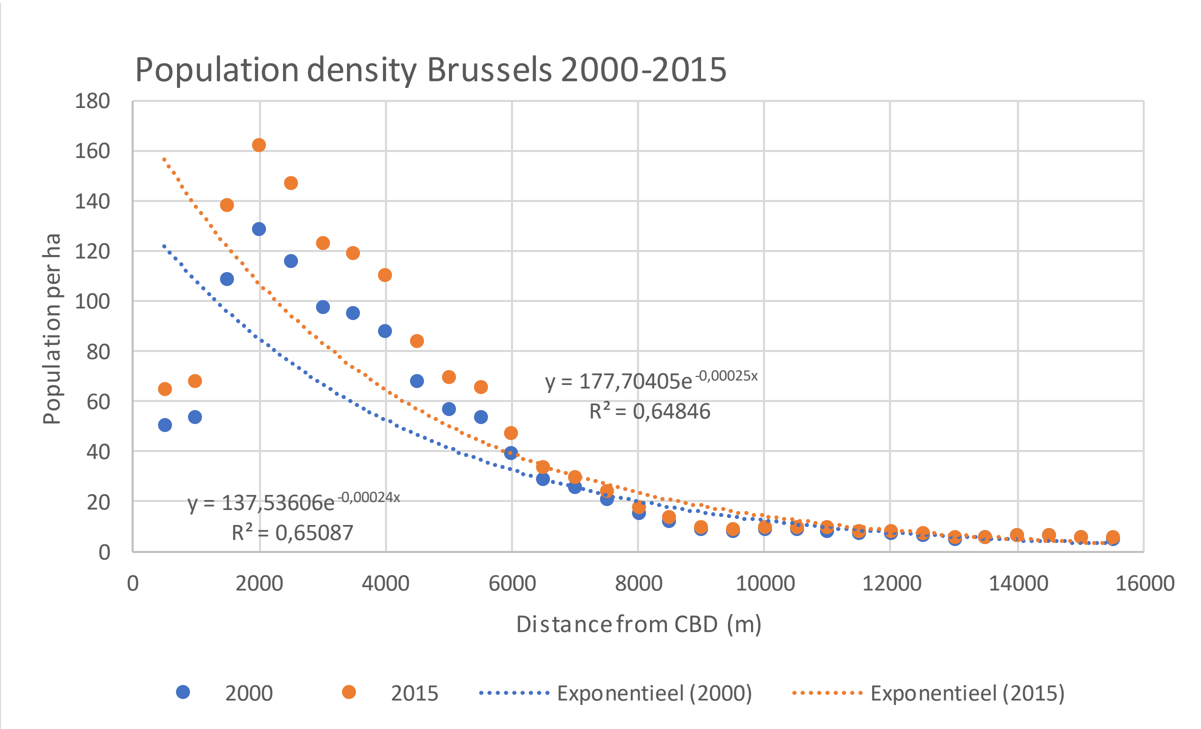
Appendix 1: Graphs of all the six cities

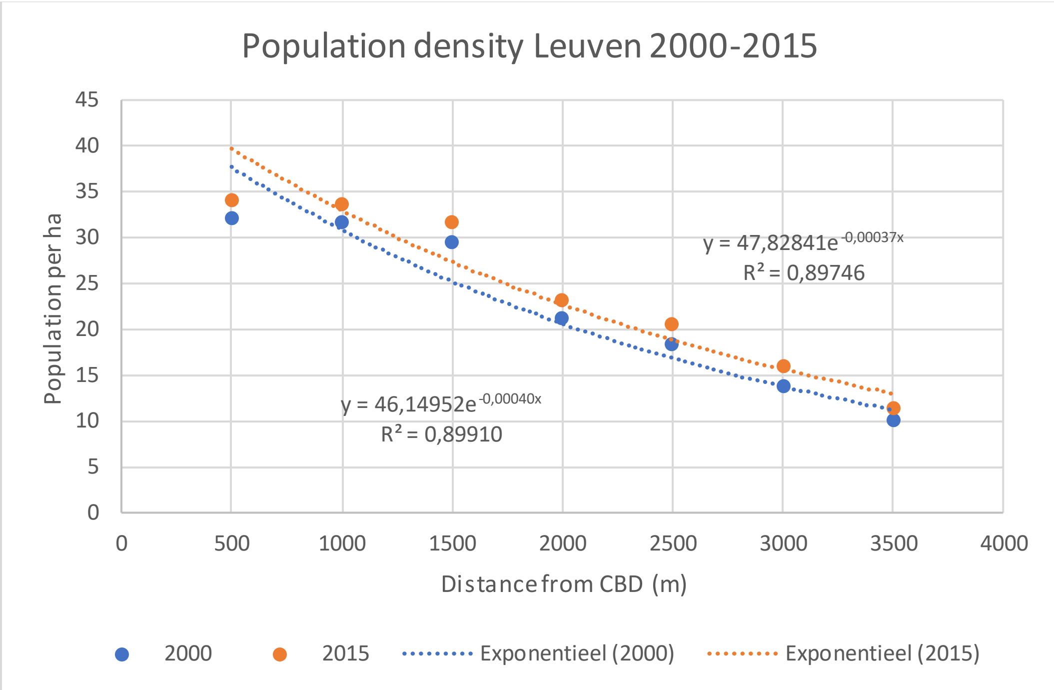
1.1: Antwerp



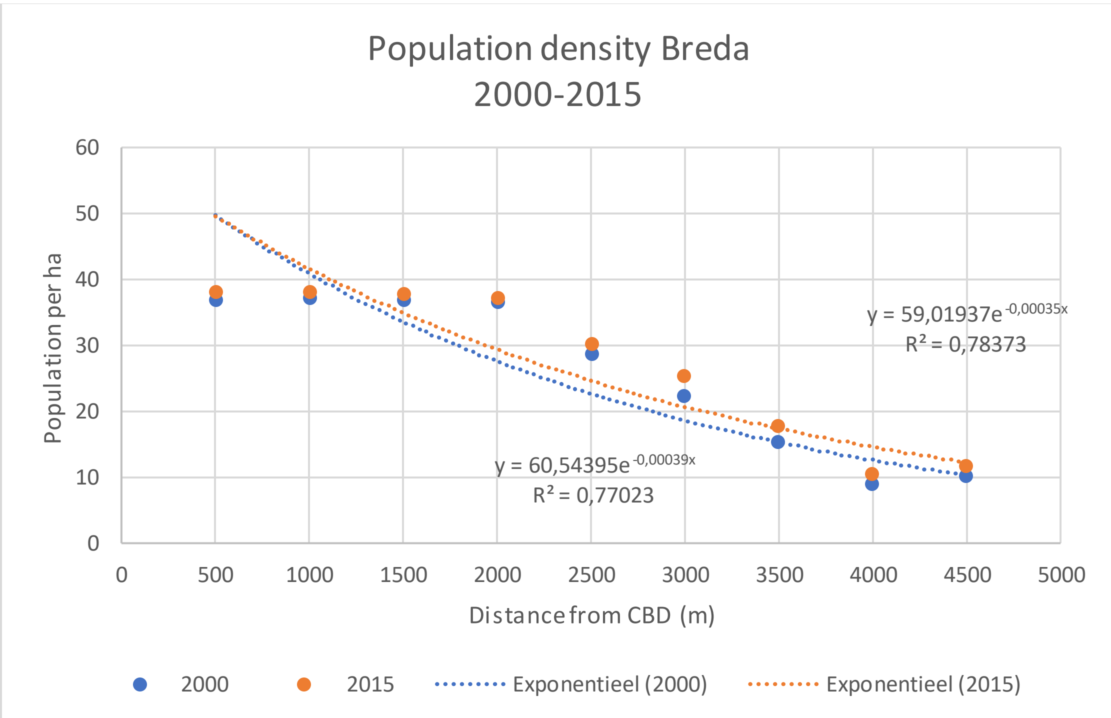
1.2: Brussels



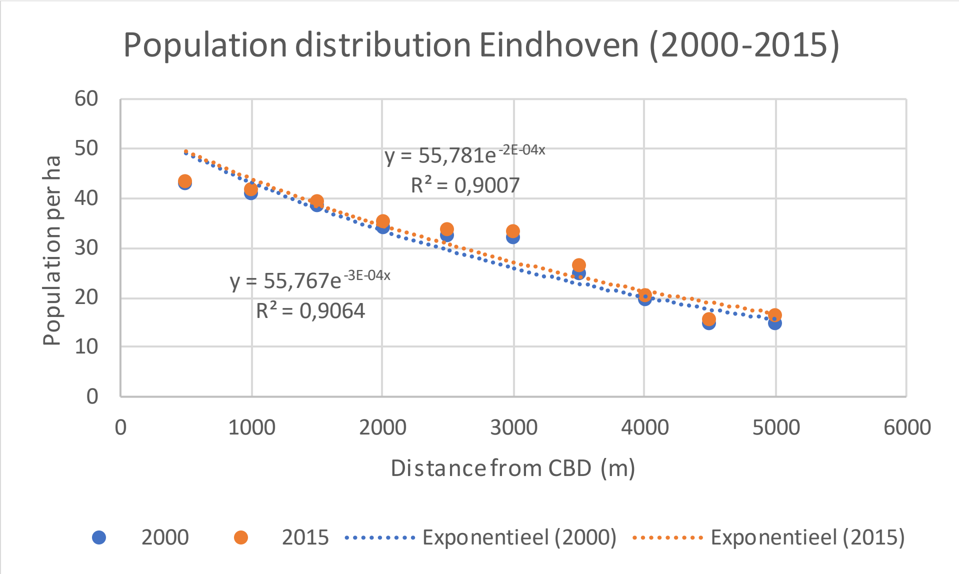
1.3: Leuven



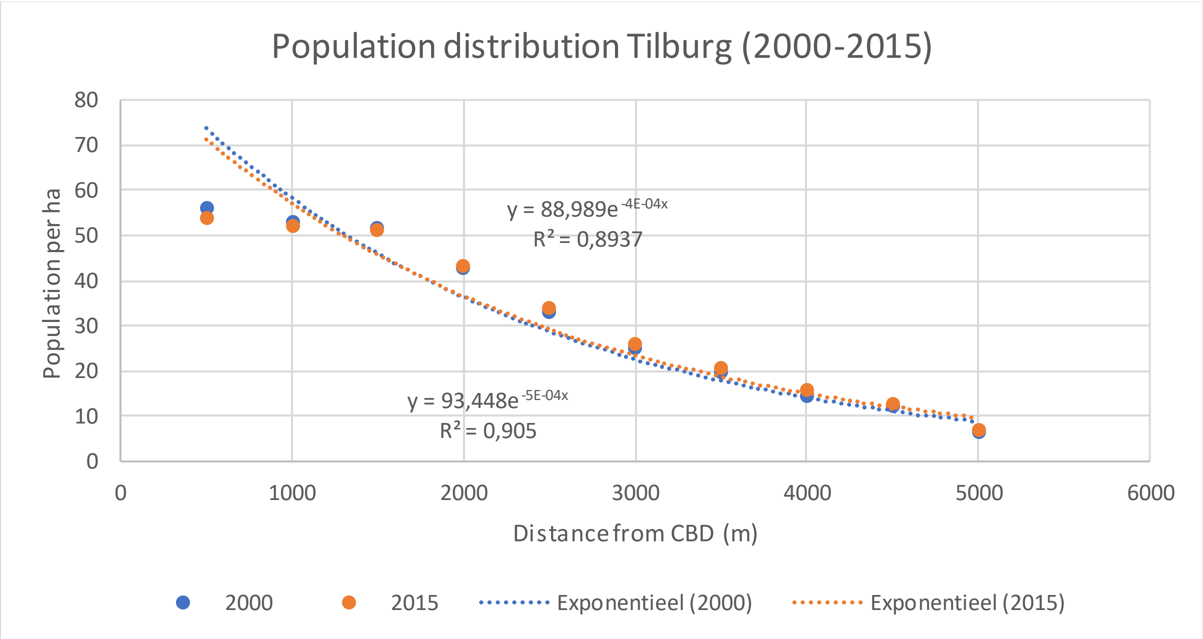
1.4: Breda



1.5: Eindhoven



1.6: Tilburg



Appendix 2: Antwerp with and without water between 2000 and 2015.