Assessment of the Normalized Difference Vegetation Index (NDVI) tool

Impact of environmental factors and precipitation in Overijssel on the reliability of the NDVI tool to determine impervious surfaces as input for water run-off models

Bachelor thesis

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Date	22-06-2023
Image	(Verbueken, 2020)

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Preface

Infront of you is my final report of my bachelor thesis with the title 'Assessment of the Normalized Difference Vegetation Index (NDVI) tool'. I carried out this thesis at the Water Noord team of Sweco in Zwolle and with this thesis, I conclude my Bachelor of Civil Engineering at the University of Twente. In this thesis, I developed a reliability part for the already existing FME NDVI tool used to determine the impervious surfaces. This part was used to assess the influence of environmental factors and precipitation on the reliability of the tool. I hope this assessment of the reliability of the NDVI tool will contribute to improving the determination of impervious surfaces used as input for urban water run-off models.

This thesis helped me develop skills that I had not learnt before such as the use of the data analysis program FME and how to set up your research. Furthermore, I enjoyed learning more about the working environment at a company like Sweco and going to the office in Zwolle.

For this in combination with the opportunity I want to thank Sweco, especially team Water Noord. Apart from this, I want to thank Theo Schipper my external supervisor at Sweco for helping me extensively during my graduation period and for being there to answer all kinds of questions. Furthermore, I want to thank my internal supervisor Trang M. Duong for her support and helpful feedback. Lastly, I want to thank Dannielle van der Wekken for helping me during the start of my research. Together, with these three persons I had great discussions about this research leading to improving my thesis even further.

I hope you enjoy reading this research.

Stijn Smeenk

Zwolle, 22-06-2023

Abstract

This thesis examines the effect of precipitation deficit and environmental factors on the determination of impervious surfaces by the FME NDVI tool in private gardens. This FME NDVI tool is used to determine the amount of impervious surface as input for water run-off models. The goal of this research is to get the output of the NDVI tool as reliable as possible in private areas.

This is achieved in this thesis by first answering the question: What is the impact of precipitation deficit on the colour differences of small vegetation in the infrared picture? The impact on the colour difference of infrared pictures is assessed since the NDVI is calculated based on the colour values of these infrared pictures. The impact is determined by developing an FME mean infrared and red value calculator used on the small vegetation areas.

The second question is: In which type of environment can the reliability of the NDVI tool be optimized? Here, the impact of environmental factors, like soil type is assessed. First, the interesting environmental factors are determined based on literature. Of these factors, the impact of soil type and tree crowns on the reliability of the tool is further assessed. This is done, by adding a reliability part to the existing tool which expresses the reliability of the outcome in a percentage.

The third question is: In what way can the use of the tool be improved concerning the NDVI threshold value in the specific environments found in the questions above? Below the NDVI threshold value, the area is considered impervious surface and above vegetation. It is found that the relation between precipitation deficit and the colour values of the infrared picture is not realistic. It is assumed that this is partly due to the spread in the dates of the pictures used and consequently the temperature difference. Therefore, it is decided that the tool is not being optimized for the precipitation classes in the third question.

There is also no clear relationship between the NDVI threshold value, and the environmental factors researched. No relationship between the soil type and the influence on the reliability of the tool is found. However, it has been found that the presence of leaves on the trees influences the reliability of the tool. These two environmental factors have nothing to do with the NDVI threshold value and because of this, these factors are not addressed in the third research question.

As a result, in the third research question, a calibration tool for the NDVI threshold value is developed which can be used to optimize the NDVI threshold value for an area of interest. This calibration tool picks a small part of the study area and calibrates the optimal NDVI threshold value for this part. Then it is assumed that this relationship holds for the rest of the study area. To check if this relation holds a validation of the calibration tool is done.

This study concludes that there is no optimal NDVI threshold value to get the highest reliability in combination with precipitation deficit, soil type and tree crowns. However, leaves on the trees negatively affect the reliability of the tool. Therefore, for a study area with a lot of trees, it is better to pick a picture without leaves on the trees to reach higher reliability. Furthermore, the calibration tool can help with getting the optimal NDVI threshold value for a certain study location resulting in optimized reliability.

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List of Abbreviations

- BAG Basisregistratie Adressen en Gebouwen
  - Database containing addresses and premises
- BGT Basisregistratie Grootschalige Topografie
  - Database containing shapes of buildings
- FME Feature Manipulation Engine
  - Data handling software
- FR Fractional vegetation cover
  - Vegetation indices
- KNMI Koninklijk Nederlands Meteorlogisch Instituut
  - Dutch national weather service
- nDSM normalised Difference Surface Model
  - Vegetation indices
- NDVI Normalized Difference Vegetation Index
  - Vegetation indices
- PDOK Publieke Dienstverlening Op de Kaart
  - Platform containing geodata sets of Dutch governments
- Qgis Quantum Geographic Information System
  - Open-source geographic information system
- SAVI Soil Adjusted Vegetation Index
  - Vegetation indices

1. Introduction

The Netherlands is getting more inhabitants each year. It has grown from 5 million inhabitants in 1990 to 17.8 million at the end of 2022 (CBS, 2023). As a result, existing cities become bigger and the countryside is getting urbanized (Lucas & ANP, 2023). However, this also creates problems since in the past chosen strategy of developing urban areas with a lot of impervious surfaces is not working well in combination with downpours of rain (Amhil, 2021). This problem is getting more significant over time due to the increased amount of precipitation in case of a downpour, this is partly because of the consequence of climate change (KNMI, 2023a).

Therefore, more knowledge is needed about the behaviour of water in urban areas, especially in the case of downpours. Nowadays, urban water systems including sewage systems are being designed based on the results of flood models. These models predict where it is likely to be flooded in case of heavy rainfall. On top of this, they predict to what level the water will rise.

To accurately model the risk of flooding, the input of the model must be as reliable and detailed as possible. An important input factor for these models is the amount of impervious surface in the urban areas. Since the behaviour and absorption of water are different depending on the land cover type (Mapleston Smith et al., 2023).

Although the area covered by impervious materials is available in public places due to public databases, it is unknown in private areas (Schipper, 2023). An important database for this is the 'Basisregistratie Grootschalige Topografie' (BGT) designed by Kadaster (*Dataset: Basisregistratie grootschalige topografie (BGT)*, 2023). A problem is that it is hard to determine the amount of impervious surface area in the private areas without measuring every area by hand based on satellite images. This is where the use of Normalized Difference Vegetation Index (NDVI) comes in handy. NDVI qualifies the greenness of a surface by measuring the difference between near-infrared and red light (GISGeography, 2022).

A tool developed by Sweco (an engineering consultancy firm) first calculates the NDVI values in a certain project area based on infrared images. The values in the resulting NDVI map will be compared with the NDVI value for impervious surfaces and this way the amount of impervious surfaces is determined.

A problem however is that the results of the tool are highly divergent. Since sometimes vegetation is considered to be an impervious surface or the other way around. Probably due to the impact of certain environmental factors and the shortage of precipitation (Schipper, 2023). Because of this, the environmental factors and the amount of precipitation before the infrared picture has been taken once a year will be addressed in this research. So, more knowledge is needed on the use of NDVI in combination with determining the amount of impervious surfaces.

Getting this knowledge will have an impact on the use of the NDVI in combination with environmental factors and the influence of precipitation deficit. This can be used for improving the determination of impervious surfaces as input for flooding models but it can also be expanded to other sectors for which the NDVI is being used such as farming.

In the first chapter, a general project background can be found, including the research questions and an outline of the report.

1.1. Project background

1.1.1. Research relevance

Sweco is the party that is leading this project. The results of this project are not only useful for Sweco but also for the clients from Sweco, such as the municipalities and waterboards. The goal of the municipalities is to reduce the impact of flooding due to heavy rainfall on their neighbourhoods. By making the output of the tool more reliable, the amount of impervious surface coverage in private areas can be known more accurately in a reduced amount of time. This is important for designing new urban water management systems, improving current water management systems or getting to understand the current water management systems better. As a result, it can help the municipalities to use urban water management systems that fit better to their situation. Consequently, the inhabitants of these areas also become part of the stakeholders. Furthermore, this improved version of the tool can be used in other countries where the same knowledge gap exists.

1.1.2. Description of Sweco

Sweco is a consultancy firm that originated in Sweden but has locations in different countries all over Europe, especially North- and West Europe. The aim of Sweco is together with clients and the knowledge of 20.000 architects, engineers and consultants, to create smart solutions for urban areas. Sweco is a consultancy firm that designs and plans buildings and community infrastructure. Furthermore, the company helps with calculations, analysis, studies and planning, design, and construction of what is to be built.

1.1.3. The study area

The study area for this study will be the urban areas in Overijssel. During the study, certain urban environments will be decided to be used based on the environmental factors and the presence of precipitation information. The environmental factors are factors like soil type, groundwater level, tree crowns or other environmental factors. The locations used for a certain environmental factor or to study the influence of precipitation will be determined based on a list of criteria and will be in Overijssel. Only the private areas of the urban areas will be studied. Since from the public areas, the necessary information related to impervious surfaces is already provided by governmental organizations. This information can be found in the open data bank of the Dutch government called Publieke Dienstverlening Op de Kaart (Pdok). In Figure 1, the study area Overijssel can be seen.

Figure 1; The study area Overijssel seen in red located in the Netherlands (Overijssel, 2023)

1.2. Problem statement and research objective

1.2.1. Problem statement

Determining the location of impervious surfaces in a certain area becomes difficult for experts if the Feature Manipulation Engine (FME) NDVI tool that they are using is not precise enough. This is especially a problem for private areas since there is no public data available related to the amount of impervious surface as is the case with public areas. The impervious surface coverage values of privately owned areas as input for the flood run-off model are therefore uncertain or need to be humanly measured to become accurate. A known source of the unreliability of the tool is the influence of dried-out small vegetation since this is mistaken by the tool as an impervious surface. Therefore, more knowledge is needed about the relationship between precipitation deficit and the influence on the infrared and red colour values of small vegetation in the infra-red picture used as input for the NDVI tool. Furthermore, advice on how to use the already existing NDVI tool better in combination with certain environmental factors is missing, these environmental factors that negatively or positively influence the use of the tool still need to be determined. In the end, the knowledge related to the influence of precipitation deficit on small vegetation impacting the infrared values needs to be combined with the environmental factors. To create a reliable NDVI tool in case of different classes of precipitation deficit in combination with the environmental factors.

1.2.2. Research objective

The objective of this research is to make the output of the NDVI tool by Sweco more reliable in private areas by finding the environmental factors that impact the reliability of the tool and determining the most suitable NDVI threshold value for the tool in combination with the amount of precipitation deficit before the NDVI value is calculated each year in one sample area for each environmental factor being addressed.

1.3. Research scope

The scope of the study is limited to improving the reliability of the output of the NDVI tool. In general, improvements will not be added to the tool since there are only 10 weeks available to do this research. Except for calibration of the NDVI value as input for the tool in combination with the environmental factors.

Furthermore, only the NDVI value of impervious surfaces as input for the tool will be part of this study, so the NDVI threshold value. Improvements on the infra-red images as input of the tool will not be part of this study.

On top of this, the research will only focus on a couple of urban areas in Overijssel as a sample and these will be chosen based on a certain environmental factor being studied which is present in this area. Or the location will be chosen since they are a suitable location to study the influence of precipitation.

1.4. Research questions

The first question concerns the impact of precipitation deficit on small vegetation since it has been found in an earlier study that this is a weak point for NDVI, see 2.3.1. The impact of the precipitation deficit will be researched using infra-red pictures because this is an input of the NDVI tool.

Question 1:
What is the impact of precipitation deficit on the colour differences of small vegetation in the infrared picture?

Sub-questions:

- By what amount of precipitation shortage is small vegetation starting to dry out?
- What is the difference in percentage between the infra-red values of small vegetation in a picture being taken at the same location depending on the amount of precipitation?

To optimize the NDVI output of the tool, it needs to be known where the tool is currently not working so well. Therefore question 2 is added to this research.

Question 2:
In which type of environment can the reliability of the NDVI tool be optimized?

Sub-questions:

- Which environmental factors and in what way can these impact the NDVI values?
- In which study area can these environmental factors be found and what is the reliability of the output of the tool for these locations?

The last question will combine the results of the first two questions to find the most optimal NDVI threshold value for certain locations.

Question 3:
In what way can the use of the tool be improved concerning the NDVI threshold value in the specific environments found in the questions above?

Sub-questions:

- What is the range of the NDVI threshold value for which the tool is working well for the different environmental factors?
- What is the most suitable NDVI threshold value for certain environmental factors in combination with the precipitation classes in private areas?

1.5. Report outline

In the second chapter background information related to the FME NDVI tool, the precipitation deficit, environmental factors, and earlier research on the use of NDVI to determine impervious surfaces is discussed. In the third Chapter, the focus is on the influence of precipitation on the drying out of small vegetation, this will be analysed using infrared pictures. The first part of this chapter consists of the process to obtain the results followed by the results, this lay-out is the same for chapters four and five. In chapter four, first, the two most relevant environmental factors will be picked based on literature and then the influence of these two factors on the reliability of the NDVI tool will be determined. In chapter five, the relevance of/and the calibration of the tool for the NDVI threshold value will be described. Which includes a validation of the developed FME calibration tool. In chapter six, the result of this study will be discussed. In chapter seven a conclusion and recommendations can be found.

2. Background knowledge

In this chapter, more information related to NDVI and the FME NDVI tool is described. Furthermore, the relevance of precipitation deficit and environmental factors on the NDVI is discussed. Lastly, earlier research on the use of NDVI for determining impervious surfaces is discussed.

2.1. The NDVI value

2.1.1. Description of the FME NDVI tool

The amount of impervious surface is determined based on an NDVI tool developed by Sweco in the program Feature Manipulation Engine (FME). This data handling software is based on the ETL approach, meaning extract, transform and load (Safe Software, sd). The software first extracts the data from a source then transforms the data to the user's needs and loads the results into a destination or data warehouse.

The amount of Impervious surface is determined by taking an infrared picture from the Netherlands as input for the tool. This picture is taken once a year during the spring and consists of three values, a red, green and infrared number. These colour numbers range from 0 to 255 (Jannink, 2023). So, infrared is part of an infrared picture together with red and green. Based on this picture the NDVI values for the studied area are calculated using the formula provided in section 2.1.2. It can be noticed that the green value is not being used to calculate the NDVI and that the near-infrared is used in the formula instead of infrared in FME. This is because near-infrared is part of infrared, so in the FME tool, the near-infrared part is still being used to calculate the NDVI (Waterschap Hunze en Aa's, sd). After the NDVI values are calculated the tool checks if the NDVI value at a location is below 0.01 (the NDVI threshold value currently being used for impervious surfaces by Sweco). If the NDVI value is below 0.01 the area is considered to be an impervious surface. For the rest of this research, the NDVI value used to check if it is an impervious surface (0.01 currently) will be called the NDVI threshold value. Another input for the tool is the level of detail of the tool. The value used for this input factor is 125 and this number will not be addressed in this research, since Sweco is confident that this is a suitable value for them. This is for Sweco the ideal balance between the accuracy and computation time of the tool. A more technical explanation of the FME NDVI tool can be found in Appendix A. In the following section, more information related to NDVI will be addressed.

2.1.2. The NDVI explained

As explained the NDVI or Normalized Difference Vegetation Index, can be used to determine if there is vegetation or impervious surface coverage in a location. The NDVI is expressed as a number ranging from -one to +one, where zero means no vegetation and close to +one means the highest possible density of green leaves. The NDVI is determined based on the different wavelengths of light, these wavelengths can, for example, be seen through a prism and all these wavelengths together make up the spectrum of the sunlight. If sunlight hits plants or other objects, parts of these wavelengths are absorbed by the object and others are reflected. It depends on the type of object, which wavelengths are being reflected, for example, the pigment in plant leaves reflects near-infrared light (from 0.7 to 1.1 µm) (Levy, 2000); *NDVI: Normalized difference vegetation index* (2023).

The NDVI value is calculated based on the visible light (reflected in the red range of the spectrum) and near-infrared light reflected by vegetation and other objects in the urban area. The formula for NDVI is the following:

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

Where: NIR is the light reflected in the near-infrared spectrum
RED is the light reflected in the red range of the spectrum

Based on the formula different classifications of NDVI values can be made, the NDVI threshold value for high vegetation (1.0 to 0.501), low vegetation (0.5 to 0.2) and non-vegetation (0.199 to -1)(Hashim et al., 2019). Based on these classifications it can be decided if there is vegetation or if it could be impervious surface coverage in the case of the non-vegetation class.

2.2. The impact of precipitation deficit and environmental factors on the NDVI

2.2.1. The impact of precipitation deficit

Based on the thresholds addressed in 2.1.2, it can also be explained why precipitation deficit makes it more difficult to determine if there is greenery or impervious surface coverage in a certain location. A result of drought on plants is water stress, the chlorophyll range in the plants reduces and as a result, the leaves turn brown (Rahmna & Hasegawa, 2012). As explained before, the leaves of healthy plants reflect near-infrared light and absorb a large range of the proportion of the red range. In the case of water-stressed or unhealthy vegetation, this function becomes reversed and the plants reflect significantly more light in the red range (Rousta et al., 2020).

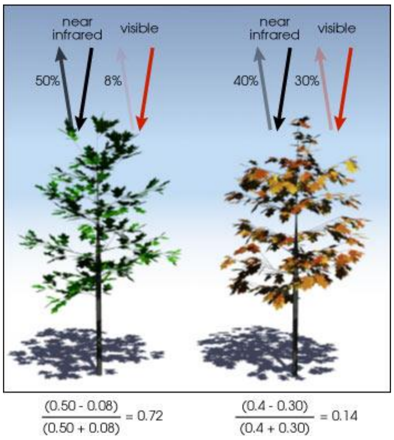

Figure 2; The NDVI value for a healthy tree (left) and unhealthy (right) (Levy, 2000)

In Figure 2, the NDVI value is lower in the case of the unhealthy tree. The NDVI value is so low, that it is in the range of non-vegetation. As a result, it is difficult to determine the difference between impervious surfaces and unhealthy vegetation based on NDVI.

2.2.2. The impact of environmental factors on the NDVI

In this study, the impact of environmental factors on the reliability of determining the impervious surface area will be addressed. First, it is important to understand the impact of environmental factors on the NDVI. An environmental factor that affects the reliability is the presence of bare soil (Bauer et al., 2007). Because bare soil is spectrally similar to impervious surfaces. As a result, the NDVI tool calculates that it is an impervious surface area instead of bare soil. Another already-known environmental factor influencing reliability is the presence of tree crowns that obscures impervious areas (Bauer et al., 2007). More information on the environmental factors can be found in chapter four including the choice of which environmental factors are addressed in this research.

2.3. Earlier research and the relevance of small vegetation

2.3.1. Earlier research on determining the land-cover type in urban areas using NDVI

Some research has been done already on using the NDVI value to determine the land cover types. A few of these attempts are discussed below.

A study published by the American Society for Photogrammetry and Remote Sensing in 2007, started focussing on the use of NDVI for determining the land cover type. In this case, the researchers used the land cover type to determine the runoff coefficient (C value). The researchers concluded that the use of NDVI value to determine the runoff coefficient was an accurate and simple approach (Thanapura et al., 2006). This shows that a clear relationship between the runoff and the land cover type exists. Furthermore, it makes clear that the NDVI value can be used to accurately determine the land cover type such that it can be used to calculate the runoff coefficient in a flood model.

A Danish study published in 2015 called 'Using Landsat Vegetation Indices to Estimate Impervious Surface Fractions for European Cities' (Kaspersen et al., 2015), focussed on the accuracy and applicability of vegetation indices. The NDVI and Soil Adjusted Vegetation Index (SAVI) are used and are converted to the impervious surface fractions by using the regression model approach. Furthermore, the NDVI is used to estimate fractional vegetation cover (FR) and consequently impervious surface fractions. The three methods (NDVI, SAVI and FR) were compared with each other to see if vegetation indices could be a suitable option to determine impervious surface coverage in cities.

One thing, which is mentioned in the Danish study is the limitations of vegetation indices for the mapping of impervious surfaces such as the influence of bare soils, tree crowns covering impervious surfaces and shadow effects from buildings. These environmental factors can be addressed in this thesis research to try to find possible solutions to limit the effect of these limitations. On top of this, in this Danish study, the three methods were found to perform almost equally accurately in determining the amount of impervious surface fractions and these types of methods perform the best in urban environments with limited areas of bare soil present (Kaspersen et al., 2015).

In 2021, research has been conducted commissioned by the Austrian Climate and Energy Fund in the Austrian Climate Research program. In this research, they used the NDVI value combined with the normalised Difference Surface Model (nDSM) to develop a classification process and applied it to the city of Innsbruck. The researchers found that a substantial portion of miscalculations occurred between neighbouring categories on the NDVI spectrum. The miscalculation that appeared to be the most common was between dry grass and concrete (20%), so they concluded that it is crucial to consider the impacts and available remedies to these types of miscalculations (Hiscock et al., 2021).

All in all, the above-mentioned studies prove that the NDVI value can be used to determine the amount of impervious surface area. Furthermore, it is also being mentioned that the are limitations and miscalculations happening well using the NDVI to determine the land cover type or decide if there is an impervious surface. These limitations and miscalculations will be a starting point in this thesis research for finding the environmental factors impacting the NDVI. On top of this, it proves that there is still room for improvement in the reliability of the use of NDVI to determine the amount of impervious surface, this is where this research focuses on. Especially the miscalculations that happened around dry grass (small vegetation) will be further addressed by taking into account the impact of precipitation deficit on small vegetation in combination with NDVI.

2.3.2. Small vegetation and the relevance for NDVI

As found in section 2.3.1, the chances of miscalculations happening in determining impervious surfaces are significant if there is dry grass around the impervious surfaces. This is due to the NDVI value being equal to the value of the impervious surface as explained in section 2.2.1. To reduce the chance of this miscalculation occurring it is important to take into account when small vegetation is starting to dry out and to find the optimal NDVI threshold value in case dried-out vegetation is present. Only small vegetation will be addressed because this was expressed explicitly as a weak point in the research commissioned by the Austrian Climate and Energy Fund in the Austrian Climate Research Program (Hiscock et al., 2021). On top of this, small vegetation is the vegetation type that is often present in urban environments. In this research, with small vegetation only grass will be considered.

3. Impact of precipitation deficit on small vegetation infra-red values

In this chapter, the influence of precipitation on the drying out of small vegetation will be addressed. More information on the relevance of this can be found in 2.3.2. In the first section, the methodology used is explained. In the second section, an alternative for the proposed monthly precipitation deficit is determined. The third section consists of the analysis of precipitation on the red and infrared values, including picking the study locations and determining the precipitation classes. The results of the analysis for the various locations in combination with the precipitation classes are described in section four.

3.1. Methodology

The goal of this chapter is to answer research question one:

- What is the impact of precipitation deficit on the colour differences of small vegetation in the infrared picture?

The method planned was to use the monthly precipitation deficit numbers obtained by Koninklijk Nederlands Meteorologisch Instituut (KNMI). However, it is found that this is not going to be a suitable method. Therefore, it is first explained based on literature and experts of Sweco, why it is not a suitable alternative. Since the precipitation shortage is not a suitable method, it is impossible to answer the first sub-question:

- By what amount of precipitation shortage is small vegetation starting to dry out?

To be able to still answer research question one, alternatives for monthly precipitation are discussed. This is done using literature and the experts from Sweco. Based on an analyse of the advantages and disadvantages the best one is picked.

To still answer research question one, the following sub-question should also be answered:

- What is the difference in percentage between the infra-red values of small vegetation in a picture being taken at the same location depending on the amount of precipitation?

This question is answered by developing an infrared and red value calculator in FME. This calculator determines the mean infrared and red value of the small vegetation of the study location. Next, it is needed to pick the study locations to answer this question, this is done by developing a list of criteria. Using this list three study locations can be picked. To assess the influence of precipitation, three precipitation classes are made using weekly precipitation values in mm of KNMI weather stations. It is important to know at which date the picture is taken over the years and what the amount of precipitation in the week before this date was. This is to be able, to assess the influence of precipitation on the values of the infrared picture. The date of the pictures is found using the ArcGIS REST services dictionary. Not every year's infrared picture is used since for each precipitation class the picture with the precipitation value that is the closest to the ideal precipitation value is used. Combining these steps the sub-question is answered and using this information the first research question is answered.

3.2. Alternative for monthly precipitation deficit

3.2.1. The reason the monthly precipitation deficit is not working with drying out of small vegetation

It is found that the correlation between monthly precipitation shortage and the impact on drying out of small vegetation is not realistic. This is because precipitation shortages are monthly values, so these are long-term values (Noome, 2023). While the drying-out process of small vegetation is short-term, small vegetation such as grass can go from yellow dry to green after a few moments of precipitation (KNMI, 2023c). This creates the situation that according to precipitation shortage, the grass should still be dried out but a few days of precipitation have happened resulting in a green grass field.

3.2.2. The considered alternatives for monthly precipitation deficit

As explained the influence of monthly precipitation deficit on the drying out of small vegetation is not realistic to be researched. Therefore, five different alternatives for the influence of small vegetation on the reliability of the NDVI tool will be discussed below and the most suitable one is used in the continuation of this research.

1. **Sample test of the NDVI value of grass**

An alternative to improve the reliability of the tool could be to take a sample of a grass field in the study area and determine the NDVI value of this sample. If the NDVI threshold value is higher than the NDVI value of grass, then the NDVI threshold value should be changed such that it is lower than the NDVI value of the grass field. Otherwise, the NDVI tool would consider the grass to be an impervious surface. To determine if this is a suitable option an analysis should be done of multiple areas to check if the reliability improves compared to using the existing NDVI threshold value of Sweco. If this is the case, it could be that this is a suitable method to reduce the number of faults related to the tool assessing grass as an impervious surface.

2. **Groundwater level**

An alternative being considered is the groundwater level. This turned out not to be a suitable alternative. Since, the groundwater level can be low while the small vegetation is still green due to precipitation (Noome, 2023). This can be compared with the long-term precipitation deficit explanation in 3.1.1 since in the long term the groundwater level can be low while the grass is still green.

3. **Precipitation**

There is a significant relationship between the monthly amount of precipitation (mm) and the monthly NDVI value. The correlation coefficient is 0.79 and the NDVI value increases linearly with the increase in monthly precipitation (Zhang et al., 2018). These values are monthly and therefore it can be uncertain what the relationship is within the month.

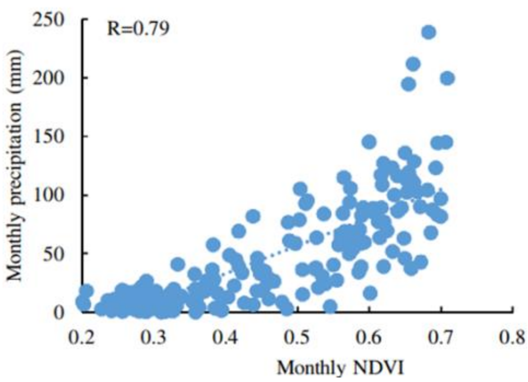

Figure 3; Relationship between monthly precipitation and the monthly NDVI (Zhang et al., 2018)

As can be seen in Figure 3, the relationship is not significant anymore from 145mm and above. In between 80-145 mm the NDVI value remains between 0.5 and 0.7. The main reason is that the growth of the plant increases with the increase of precipitation, as a result, the NDVI value will gradually increase too (Zhang et al., 2018). After a certain time, the soil underneath is covered with vegetation and the NDVI value does not change anymore.

4. **Temperature**

The correlation between the monthly temperature and monthly NDVI value has a correlation coefficient of 0.89 (Zhang et al., 2018). Meaning that the vegetation coverage gradually improves with the increase in monthly temperature.

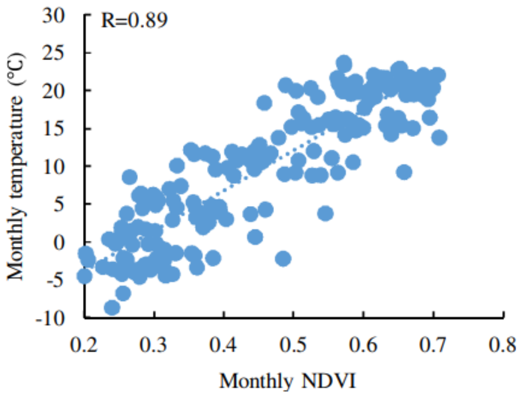

Figure 4; Relationship between monthly temperature and the monthly NDVI (Zhang et al., 2018)

The relationship can be seen in Figure 4, however, it is unknown how the daily NDVI value will behave compared to high temperatures. This is relevant for the drying out of the small vegetation since due to the small root system this could be severely affected by day-to-day changes in temperature. But this is still unknown, according to Zhang et al., the most optimal temperature for NDVI is the range from 13-23 °C.

5. **Soil moisture**

The correlation coefficient is 0.65 for the relation between NDVI and soil moisture. As can be seen in Figure 5, the NDVI value increases with the increase in soil moisture. It can also be seen that if the soil moisture is in the range of 25-33%, the NDVI value remained between 0.5 and 0.7.

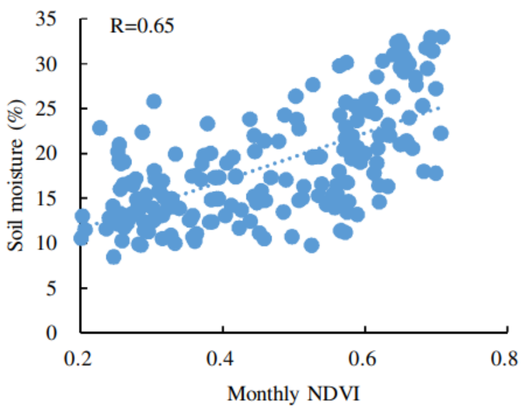

Figure 5; Relationship between soil moisture and the monthly NDVI (Zhang et al., 2018)

3.2.3. Picking the alternative for precipitation deficit

The most suitable alternatives out of the five will be determined based on addressing the advantages and disadvantages of each.

The first alternative is the sample test of the NDVI value of grass. It is unclear if this will be a suitable method, it has namely not been addressed in literature before. Furthermore, the methodology needs to be completely adjusted to implement this method into the research. That is why, this will not be a suitable alternative.

The second alternative is the groundwater level, this is not a suitable alternative since it is unclear if there is a relationship with the NDVI. Another reason why the groundwater level is not a suitable option is that the groundwater level can be low and the grass is still green due to short-term precipitation. Therefore, this method will not be used in this research.

The next alternative, namely the precipitation can be the most easily implemented within the already existing method. Since the monthly precipitation deficit will be replaced by short-term precipitation (a week before the picture has been taken). Furthermore, there is a significant relationship between precipitation and the NDVI. This results in this method becoming the most suitable alternative.

The soil moisture will be less suitable than the precipitation because the relation is less significant compared to precipitation. Furthermore, it will overlap too much with the research of question two on environmental factors such as soil type.

The temperature is a suitable alternative but it will take more time to implement this into the already existing research method compared to short-term precipitation. As a result, it could be that this research would become too complex for the available timespan. That is why short-term precipitation will be the used alternative in the continuation of this research question.

3.3. Influence of weekly precipitation on the infrared and red value

In this section, the analysis of the influence of precipitation on the infrared and red values of small vegetation for three locations in Overijssel is done. The locations are picked based on criteria and the precipitation classes are determined based on data from the KNMI (Koninklijk Nederlands Meteorlogisch Instituut).

3.3.1. Implementation of the infrared and red calculator in FME

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3.3.2. Criteria for picking the locations

To determine if a location is suitable for assessing the influence of precipitation classes on the mean infrared and red values of small vegetation a few criteria are used. These criteria can be found underneath.

- A study location should be within a 10 km radius of a KNMI weather station, such that the precipitation numbers are as reliable as possible for this location.
- At least 25 km between the different project locations, to make sure that the locations are spread over the province.
- Only a limited amount of change to the land cover type of the area, based on a comparison of Landsat pictures.
- Small vegetation is present in the gardens, with small vegetation only grass is being considered.
- A study location is not severely influenced by high temperature, high intensity of light and dry wind, all of which are leading to the evaporation of water from the soil leading to the plant not having enough water available in the soil.
- A study location needs to be in an urban area.

3.3.3. The picked locations

The picked locations in Overijssel are the urban areas of Hardenberg, Hengelo and Berkum. These places all have their own KNMI weather stations or are close by, are at least 25 km apart from each other and check all the other criteria. These weather stations are all located outside the urban areas. To create a bit of diversity between the house types of the different areas, in the study area of Hardenberg mostly terraced houses can be found, in Hengelo mostly semi-detached houses and in Berkum detached houses. An example of the different house types can be seen in Figure 7.

Figure 7; Different house types, terraced house, semi-detached house and detached house (ANP, 2016; Groothuisbouw, 2016; Verstoep, sd)

A detailed explanation of the study locations including the locations of the KNMI weather stations can be found in Appendix C and Figure 8 shows a map with a close-up of each location.

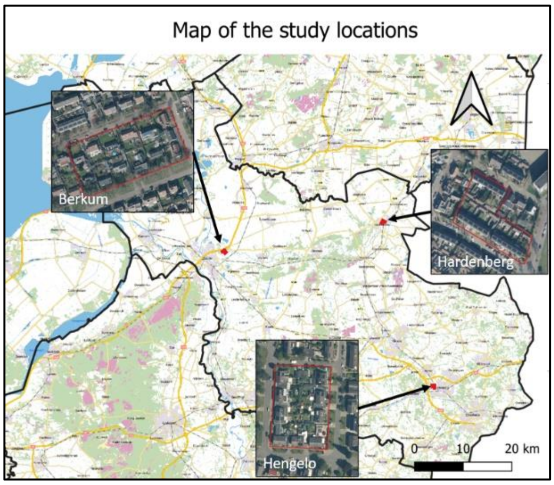

Figure 8; Map of the study locations (red) with a close-up of each location

3.3.4. The precipitation classes

A week of precipitation is considered, furthermore, the values are based on low, normal and high precipitation values in the Netherlands during spring. Since this is the time of the year that the infrared pictures are taken. According to KNMI, the spring is from March until May and in these three months, the average precipitation of multiple years is 148 mm (Homan, 2022). The months consist of thirteen weeks, resulting in an average precipitation of 11.4 mm per week. Therefore, this will be the ideal medium value. The lower boundary is half of the ideal medium value and the upper boundary is twice the ideal medium value. This is done to evenly spread the precipitation values among the different precipitation classes. To create classes, the number of the lower boundary of the high class ends with .81 and of the low precipitation class the higher boundary ends with .69.

The spring of 2020, was considered to be a dry spring with a total precipitation of 77 mm and the month of April and May of this year are in the top ten of the driest April and May in the Netherlands (De Wijs, 2020). Within the spring period, the seven continuous days with the lowest amount of precipitation are considered, while eliminating the two days with the lowest precipitation values of the spring. In April alone there were 25 days without any precipitation in De Bilt, with multiple periods longer than seven days. Therefore, for the low precipitation class, an ideal value of zero mm is used.

A wet spring in the Netherlands was the spring of 2006, with a value of 187 mm this was one of the wettest springs in the 21st century (Sluijter, 2006). Within the spring period, the seven continuous days with the highest amount of precipitation are taken into account, while eliminating the two days with the highest precipitation values of the spring. These are the ninth of March (23,8 mm) and the 27th of March (15,8 mm), the highest precipitation sum of seven days without these values present is from the 21st of May until the 27th of May. The precipitation sum of these seven days is 49.2 mm. So, the ideal high precipitation value is 49.2 mm per week. The precipitation classes can be seen in Table 1.

Table 1; The precipitation classes

Precipitation Class	Lower boundary (mm per week)	Ideal value (mm per week)	Upper boundary (mm per week)
High	22.81	49.2	-
Medium	5.7	11.4	22.80
Low	0	0	5.69

3.3.5. The precipitation values and aerial photo date for the locations

The dates the pictures are taken are based on the flight lines which can be found in the ArcGIS REST services dictionary (*Blokindeling, vlieglijnen en voortgang HRL of LRL vluchten*, 2016-2023). The amount of precipitation in the seven days before the picture is taken is based on the daily precipitation measurements of KNMI. The results of Hardenberg can be seen below in Table 2 as an example and for the other two locations, it can be found in Appendix C.

Table 2; The aerial photo date for the different years and the corresponding amount of precipitation (mm) in Hardenberg

Aerial Photo Date	Amount of Precipitation (mm)
09-02-2023	11.6 (photo has been taken, not available)
22-06-2022	2
15-04-2020	0
01-04-2019	3.7
18-04-2018	8.2
11-05-2017	1.3
10-04-2016	16.8

3.4. The results

In the tables below the results of the study can be seen and underneath the tables an explanation of the results.

*Table 3; Values of infrared and red for different locations and precipitation shortage classes. * Value officially not located within the high precipitation class.*

Location	Precipitation Class	Date	Amount of precipitation (mm)	Infrared (index 0)	Red (index 1)
Hardenberg	Low	15-04-2020	0	160.23	118.52
	Medium	18-04-2018	8.2	96.00	72.39
	High	-	-	-	-
Hengelo	Low	06-04-2020	0	152.73	107.13
	Medium	16-06-2022	15.4	134.43	91.78
	High	15-02-2019	30.3	144.17	98.03
Berkum	Low	15-04-2020	0	157.28	100.73
	Medium	20-04-2018	7.5	131.03	89.88
	High	15-02-2019	22.6*	136.72	99.79

Table 4; The differences in the percentage of the infrared values between the classes

Location	Difference Infrared value low-medium (%)	The difference Infrared value medium-high (%)	Difference Infrared value low-high (%)
Hardenberg	-40.08		
Hengelo	-11.98	7.25	-5.60
Berkum	-16.69	4.34	-13.07

Table 5; The difference in the percentage of the red values between the classes

Location	Difference Infrared value low-medium (%)	The difference Infrared value medium-high (%)	Difference Infrared value low-high (%)
Hardenberg	-38.92		
Hengelo	-14.32	6.81	-8.49
Berkum	-10.77	11.03	0.94

It can be seen in Table 3, that there is a big difference in time between the dates of the pictures used. This is taken into account during the process and it has been noticed that there is no significant change in the purpose of the surfaces in the gardens. Therefore, it is not a problem for the reliability of the results that there are so many years between the different pictures.

As can be seen in Table 3, the infrared index is higher than the red index. Furthermore, the infrared and red values of the low precipitation class are significantly higher than the value of the medium class, as can be seen in Table 3 and Table 4. One thing, which can also be seen is that the value of the high class is larger than the medium class. An explanation for the larger medium value compared to the high value could be the influence of the date when the picture has been taken. In Hengelo and Berkum the medium picture is taken at least two months after the high precipitation picture. As can be seen in Figure 6, the temperature is closely related to the NDVI value which is calculated using the values of infrared and red. For example, in Hengelo, the average temperature in June is significantly higher than the temperature in February as can be seen in Figure 9. This can explain the difference between these classes, but more research is needed to reach this conclusion.

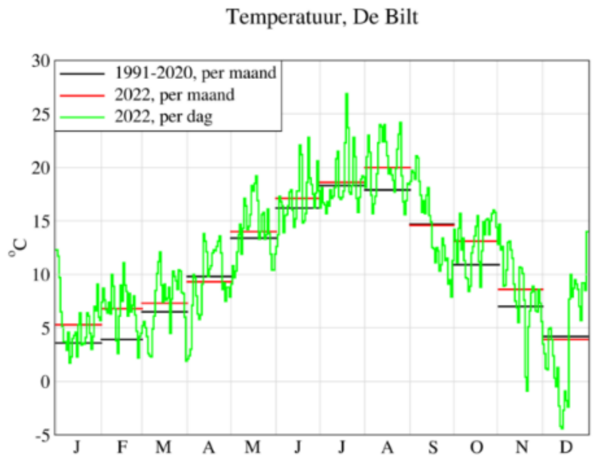

Figure 9; The temperature in De Bilt spread over the years (KNMI, 2023b)

4. Environmental factors that impact the reliability of the NDVI tool

In this part of the research, the influence of environmental factors on the reliability of the NDVI tool is addressed. First, the methodology can be found. In section two, it is decided which environmental factors are addressed. Information on the FME reliability part added to the NDVI tool, which is used to assess the reliability can be found in section four.

4.1. Methodology

The goal of this chapter is to answer research question two:

- In which type of environment can the reliability of the NDVI tool be optimized?

This question will be answered using sub-questions, the first sub-question:

- Which environmental factors and in what way can these impact the NDVI values?

The sub-question is answered by doing literature research on the relevant environmental factors. After the relation of each environmental factor with the NDVI is discussed, the two most relevant factors are chosen. After the relevant environmental factors are determined it is needed to answer the second sub-question to be able to answer research question two. The second sub-question is:

- In which study area can these environmental factors be found and what is the reliability of the output of the tool for these locations?

To determine where these two environmental factors can be found a list of criteria is made for each environmental factor. Based on these lists the locations for the environmental factors are picked. Next, the FME reliability part is developed to be able to express the reliability in a percentage. This reliability part is made by creating a grid of dots over the study area in the program FME. For each dot, it is determined if it is an impervious surface according to the tool and in real life. If the dot is impervious surface in real life and according to the tool then this dot is seen as reliable. So, the reliability percentage is the total number of dots that is reliable divided by the total number of dots in the grid and multiplied by a hundred. After this is done, the results using the FME reliability part for the different locations of each environmental factor are analysed. This way, the sub-question and the second research question are answered.

4.2. Environmental factors being considered

Different environmental factors can impact the NDVI value of a certain area. The following, environmental factors are considered.

1. Soil type
2. Presence of bare soil
3. Tree crowns
4. Water bodies
5. Shadows of buildings

4.2.1. Soil type

Soil type can influence the NDVI tool in two ways. First, the soil type influences the capacity of the ground to retain water. This is important for the NDVI since the NDVI is a vegetation index and the value is depending on the greenery of the vegetation. Soils with smaller particles such as clay and silt have more surface area in comparison with sandy soils with large particles allowing the soil to hold more water (Ball, sd). So, soil with smaller particles can retain more water than soil with large particles.

Another factor influencing the water-holding capacity of different soil types is the percentage of organic matter within the soil (Ball, sd). As the percentage increases, so does the water-holding capacity due to the affinity of organic matter to water.

In Figure 10, the water availability for three distinct types of soil can be seen. Above the field capacity, the soil is unable to absorb the excess or gravitational water. From the field capacity to the wilting point, the water level has two stages, namely available water with no plants stress and available water with the plant possibly having water stress. From the wilting point on the plant will start to have water stress. The levels depend severely on the type of soil, for silty soil (small particles) the water levels are higher than loam (mean particles) and sand (large particles).

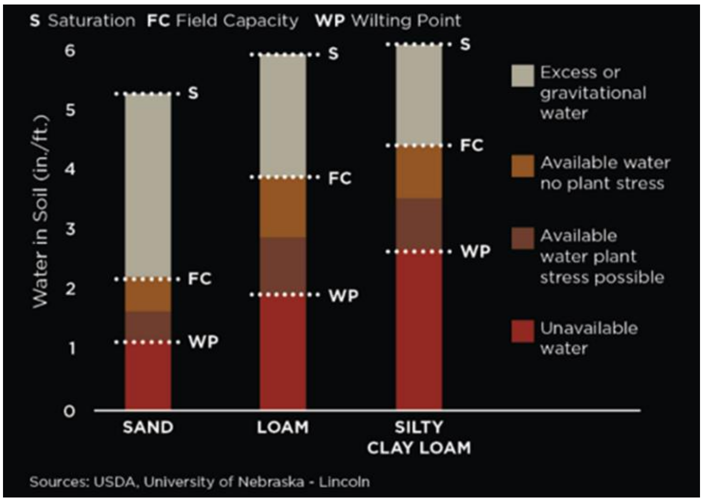

Figure 10; Available water for plants per soil type (Ball, sd)

Soil type also affects the NDVI directly, since each soil type has its spectral reflectance curve and depending on the soil type the spectral reflectance curve is more or less similar to the curve of impervious surface (Jia et al., 2017). According to the ITC department of Twente, a spectral curve is: "The curve showing the portion of the incident radiation that is reflected by a material as a function of wavelength. Sometimes called spectral signature" (Twente, 2020). So, the curve has the wavelength (µm) on the x-axis and the reflectance (%) on the y-axis.

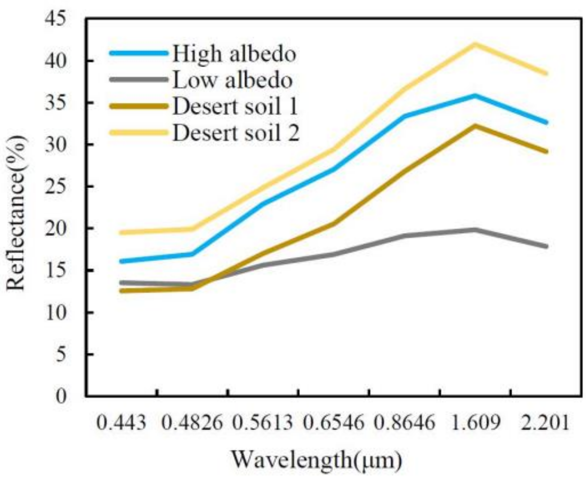

Figure 11; Example of the spectral curves of different soil types and impervious surfaces in Yinchuan China (Jia et al., 2017)

Figure 11, shows how close the different curves can be related to each other. This also affects the NDVI tool since this uses the wavelengths of light to calculate the NDVI value, see section 2.1.2.

Since the soil types in the province of Overijssel are not the same across the whole province, it could be that the tool is more reliable in one part of the province compared to another part with a different soil type.

4.2.2. Presence of bare soil

Bare soil is often mistaken for impervious surface since the NDVI values are closely related to each other (Lu et al., 2011). This is due to the spectral curves as explained in section 4.2.1 about soil type. Therefore, the influence of spectral curves will not be explained twice.

4.2.3. Tree crowns

Based on multiple studies the presence of tree crowns has been pointed out as a limiting factor of the use of NDVI to determine the amount of impervious surface (Bauer et al., 2007; Lu et al., 2011). The tree crowns limit the determination of impervious surfaces in two ways. Namely, directly by the leaves covering the impervious surface and indirectly due to the shadows on the ground resulting in the tool assessing bare soil or grass to be impervious surface. It has also been found that in case the resolution of the pictures is higher the influence of shadow on the outcome of the tool will also be higher (Lu et al., 2011).

4.2.4. Water bodies

The tool is mainly used to determine the amount of impervious surface of private areas. It is not that common to have water bodies located in a small garden but it is often addressed in the literature that water bodies are one of the factors that confuse NDVI tools while determining impervious surfaces (Feng & Fan, 2019; Lu et al., 2011). This is due to the fact, that water bodies are quite dark seen from the sky and are therefore being confused with dark impervious surfaces (Feng & Fan, 2019). Because the spectral curves are closely related to each other.

4.2.5. Shadow of buildings

The shadow of buildings is closely related to the tree shadow problem. However, the shadow of buildings is only making the areas darker and the buildings are only in small amounts blocking the impervious surface. These shadows are covering the vegetation and reduce the vegetation indices signal of these areas and as a result influence the strength of the relationship between vegetation indices and impervious surface fractions (Bauer et al., 2007).

4.2.6. The two environmental factors chosen

The soil type will be one of the factors addressed in the continuation of this research because it influences the NDVI value in two ways. Namely, the spectral curve is closely related to the one of impervious surfaces and the moisture content of the soil influences the growth of vegetation. On top of this, it has a considerable influence on the relationship between the presence of bare soil and the soil being an impervious surface. As a result, only the soil type will be addressed in this research of these two. Another relevant factor is the presence of tree crowns, this also influences the reliability of determining impervious surfaces in two ways. Namely, by directly blocking the view on the impervious surface and confusing the tool by determining that there is more impervious surface due to shade. There is also a lot of overlap between the tree crowns and the buildings since they both produce shade and in this way influence the NDVI tool. Because the tree crowns limit the NDVI in an additional way compared to the buildings only the tree crowns are addressed in this research. Since it is not likely to find large waterbodies in private urban areas, this environmental factor will not be addressed in this research.

4.3. Study locations to assess the influence of environmental factors

4.3.1. The criteria used to pick the locations

To determine if a location is suitable to assess the influence of environmental factors on the reliability of the tool a few criteria are used. These criteria can be found underneath and are separated for soil type and tree crowns.

Soil type locations criteria:

1. At least 25 km between the different project locations, to make sure that the locations are spread over the province of Overijssel.
2. At each location, a drill sample point of the Basisregistratie ondergrond regis II is present within three km from the study area.
3. Each location has one of the three most common soil types of Overijssel present and each soil type is at least present at one location.
4. Each location needs to be in an urban area

Tree crowns locations criteria:

1. At each location, at least eight houses should be considered, since this is a realistic value for the number of front gardens that could be covered by a row of trees.
2. At least one PDOK infrared picture is available with leaves on the trees and one without leaves from 2016 until 2023. This way, it can be checked if the presence of leaves on the trees has a considerable influence on the reliability.
3. The layout of the front gardens should not have been changed significantly from 2016 until 2023.
4. At least seventy percent of the front garden should be covered by the leaves of the trees to be able to assess the influence of leaves on the trees. Seventy percent because the value should not be too low to assess the influence of leaves and not be too high since otherwise, it is too hard to find locations.
5. At least five square meters of pavement should be present per garden.
6. Google Streetview images should be available of the street, to improve the reliability of the drawn pavement.
7. Each location needs to be in an urban area.

4.3.2. The locations for the factor soil type

It is important to take the soil type into account, the most common soil type in Overijssel are human podzol soils and calcareous sandy soils (Overijssel, 2022). Other common soil types are clay in the east of the province and in the west of the province peat. As the third soil, clay will be considered since this is a more common soil in urban areas than peat. Peat soils are mostly used as grassland since these are too wet to be used for other purposes (Wesseling, 2023). The soils and the place are:

1. Human podzol soils (Staphorst)
2. Calcareous sandy soils (Haaksbergen)
3. Clay (Zwolle)

The different study locations can be seen in the map of Figure 12 on the next page.

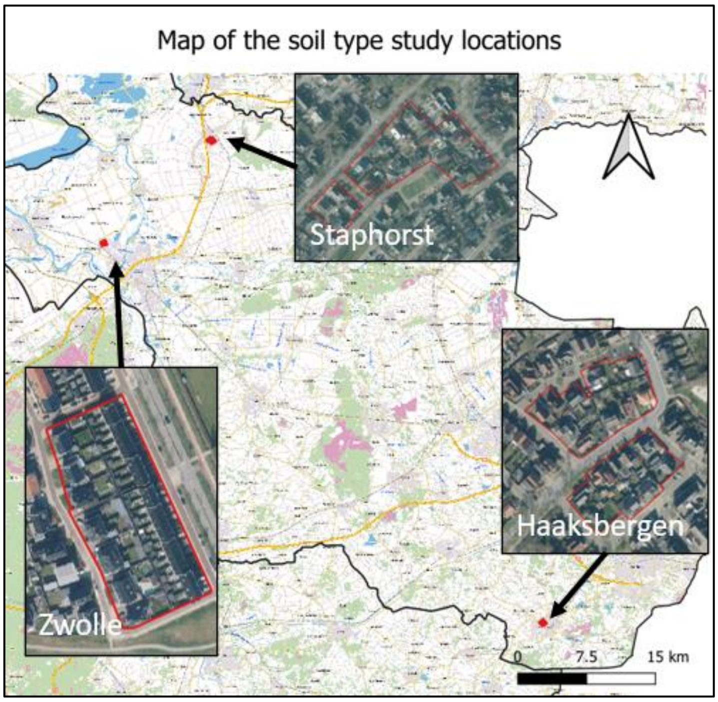

Figure 12; Map of the soil type study locations (red) with a close-up of each location

It is often the case that the first 0.4 m1 of a soil is sand this is being done in urban areas to increase the stability of the soil (Kollaros & Athanasopoulou, 2016). As a result, the spectral reflection of the soil at different locations will be the same since this only depends on the topsoil namely sand.

The soil type underneath the sand topsoil still influences the capacity of the ground to retain the water. This is important for the NDVI since the NDVI is a vegetation index and the value is depending on the greenery of the vegetation. Therefore, the soil type underneath the sand layer is still considered.

A more detailed explanation of the study locations including a soil sample and the soil classification can be found in Appendix D.

4.3.3. The locations for the factor trees

The reliability related to the presence of trees is assessed by using homes where the front gardens are covered by trees. It depends on the year at which date the trees are getting their leaves, therefore it will be checked on the infrared picture per year if the trees have leaves or not (Vliet & Bron, 2018). In Figure 13, two pictures of the same location can be seen but then a year apart from each other. It can be seen, that there is a significant amount of leaves on the fifth of April 2017 but no leaves at all on the fourth of April 2018. Therefore it is important to check for leaves in the infrared picture.

Figure 13; The Pronus plant with leaves in 2017 and no leaves at all in 2018 (Vliet & Bron, 2018)

For each location, a date that the picture is taken with leaves on the trees and a date without leaves is used. The locations that are used are Nijverdal, Zwolle, Raalte, Luttenberg and Oldenzaal. These locations all check the criteria of 4.3.1. The different study locations can be seen in the map of Figure 14 and more explicit information about the locations can be found in Appendix E.

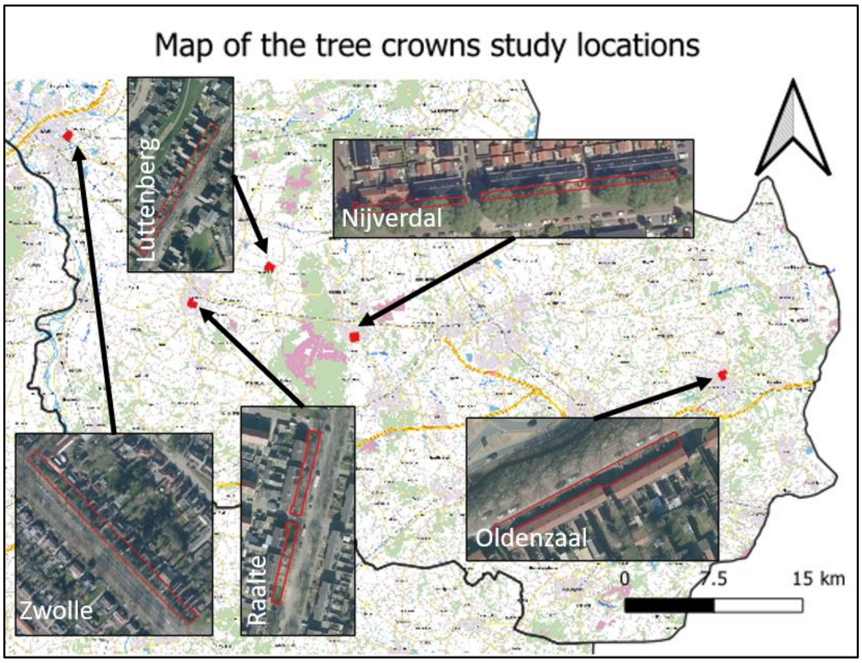

Figure 14; Map of the tree crowns study locations (red) with a close-up of each location

4.4. The FME reliability part

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4.5. The results of the influence of environmental factors on the reliability

4.5.1. The influence of soil type on the reliability

The outcomes of the influence of the different soil type locations on the reliability of the tool can be seen in Table 7. It also includes the overestimation and underestimation of the tool, which can be used to check where the unreliability is coming from. The results are found using an NDVI threshold value of 0.01. It needs to be considered that the determination of the pavement areas is influenced by uncertainty since this is done based on areal pictures and Google Streetview of the area. It is assumed that the total uncertainty related to this step is ten percent. The largest part of the uncertainty comes from trees covering the paved area and back gardens which cannot be checked using Streetview.

Table 7; The reliability results of the different soil types

Location	Environmental factor researched	Reliability of the Tool (%)	Overestimation (%)	Underestimation (%)	Other comments
Staphorst	Human podzol soils	63.23	31.11	5.66	A few trees cover the front gardens
Haaksbergen	Calcareous sandy soils	60.33	34.39	5.29	A few trees cover the front gardens
Zwolle (Stadshagen)	Clay	63.61	32.32	4.08	

In Table 7, the different soil types are not influencing the reliability of the tool by a large amount. This can also be explained by the different drill samples of the areas since most of them still largely consist of sand. Another factor to consider is the large amount of overestimation compared to the amount of underestimation. The tool determines that there is more pavement present than is the case in real life.

4.5.2. The influence of tree crowns on the reliability

The outcomes of the reliability of the tool for the front gardens underneath the trees of the five locations can be seen in Table 8. For each location, the picture of 2018 has been used for the situation with no leaves on the trees in front of the houses and 2020 for the situation with leaves. There is still uncertainty related to the drawing of the pavement areas but this is only five percent since the front gardens situation has been checked using Google Streetview.

Table 8; The reliability of the tool underneath trees with and without leaves

Location	Leaves on trees	Picture date	Reliability of the Tool (%)	Overestimation (%)	Underestimation (%)	Other comments
Nijverdal	No	19-04-2018	72.15	11.42	16.43	Gravel in gardens
	Yes	06-04-2020	46.54	0.06	53.40	Gravel in gardens
Zwolle	No	20-04-2018	84.90	4.66	10.44	Large front gardens
	Yes	15-04-2020	75.24	0.04	24.72	Large front gardens
Raalte	No	19-04-2018	68.48	21.08	10.54	Relatively a lot of bare soil
	Yes	22-03-2020	72.20	0.12	27.68	Relatively a lot of bare soil
Luttenberg	No	19-04-2018	79.98	8.53	11.49	Large front gardens
	Yes	22-03-2020	67.23	0.41	32.36	Large front gardens

Oldenzaal	No	19-04-2018	70.05	23.02	6.93	Relatively a lot of bare soil
	Yes	06-04-2020	63.10	0.38	36.52	Relatively a lot of bare soil

In Nijverdal the reliability of the tool with leaves on the trees is at least 25 percentage point (pp) less reliable. The difference between these locations can be explained because of the leaves blocking the pavement resulting in the tool thinking the paved area is greenery this can be seen by the high percentage of underestimation. One thing, to be noticed is that gravel in the gardens is assessed by the tool as an impervious surface and drawn in this test as an impervious surface. While water can drain through the gravel into the soil underneath the gravel.

At the location in Zwolle, the reliability of the tool is way higher than for the location in Nijverdal. This can be explained by the fact that the houses in Zwolle are detached houses with large front gardens, which means that if the trees are covering the gardens the tool is still correct about the fact that there is a lot of green.

At the location in Raalte, the reliability of the tool is worse in case there are no leaves on the trees. This is mainly due to a high percentage of overestimation, one of the explanations for this can be that there was relatively a lot of bare soil present. This is a known cause for NDVI tools determining that the surface is impervious (Lu et al., 2011).

At the location in Luttenberg, the reliability percentages are quite high compared to the other locations. This is due to the fact, that the houses are detached houses or semi-detached houses with larger gardens. The same argument as for Zwolle related to the higher quantities of greenery can therefore explain this case.

At the fifth location in Oldenzaal, there is a high percentage of overestimation in case of no leaves. This is closely related to the argument of Raalte related to the presence of bare soil. Furthermore, the underestimation is high in the case of leaves present. This is due to the same argument as of Nijverdal related to the leaves blocking the pavement resulting in the tool assigning that this is a green area.

A point of attention, for this study, is the fact that the study areas in this research are relatively small in comparison with the size of the study areas the tool would normally be used on by the experts of Sweco. This will probably result in less extreme results since not all the areas are covered by trees.

All in all, it can be said that the leaves of trees negatively affect the reliability of the tool. The influence of trees is relatively high in the case of terraced houses compared to detached houses.

5. Calibration of the NDVI FME tool

Since the effect of the external vector soil type is almost none, see 4.5.1, it is not realistic to calibrate the tool for the different soil types present in the province of Overijssel. The other external factor addressed was the influence of tree leaves blocking the pavement. The outcome of this part, see 4.5.2, was that it is better to take a picture that is older but has no leaves on the trees than a picture that is the most up-to-date with leaves present. As a result, it does not make sense to optimize the NDVI threshold value for this. Furthermore, based on the experience of the experts from Sweco it can be said that the optimal NDVI threshold value depends on the location (Schipper, 2023). Therefore, it is decided to develop an FME calibration tool for the NDVI threshold value which can be run before the amount of impervious surface will be determined by the FME NDVI tool.

5.1. Methodology

The goal of this chapter is to answer the third research question:

- In what way can the use of the tool be improved concerning the NDVI threshold value in the specific environments found in the questions above?

To be able to do this it was planned to answer the following sub-question:

- What is the range of the NDVI threshold value for which the tool is working well for the different environmental factors?

As described in the introduction of this chapter, it does not make sense to research a relationship between the NDVI threshold value and the two environmental factors. However, to improve the use of the tool concerning the NDVI threshold value, a calibration tool for the NDVI threshold value is developed. This tool can be used before the amount of impervious surface is determined using the FME NDVI tool. Part of developing this calibration tool is determining a calibration range, which is based on literature in combination with the findings obtained during the research of the first and second research questions.

The idea was to answer the third research question by using the following sub-question:

- What is the most suitable NDVI threshold value for certain environmental factors in combination with the precipitation classes in private areas?

As an alternative for this sub-question, the developed FME calibration tool is validated. This is done by checking if it is realistic to assume that the optimal NDVI threshold value for a street is the same as for the whole area consisting of multiple streets. If this is the case, then the calibration tool can be a suitable addition to the use of the existing FME NDVI tool. Based on the results of the validation it is determined if this is a good way to improve the use of the tool concerning the NDVI threshold value. All in all, the third research question is answered using the obtained results.

5.2. The FME calibration tool

The goal of the calibration of the NDVI threshold value of the FME tool is to optimize the reliability of the NDVI tool. This will be achieved by running the calibration tool for a small part of the study area because all the pavement needs to be drawn in by hand and for a large study area this would take too much time. Resulting, in the situation that the calibration process is not being used by the experts. The calibration tool will use the reliability part earlier designed in this research, see section 4.4 and will run it for a wide range of NDVI threshold values. The calibration tool will then show the three NDVI threshold values with the highest reliability. It has been chosen to show three values because the over- and underestimation of the different NDVI threshold values can be different. If the reliability values of the number one and two are remarkably close to each other, but there is a large difference in the percentage of underestimation, in that case, it is most likely that the expert will choose the option with the low percentage of underestimation. Because the amount of impervious surface will be mostly used as input for flooding models and therefore it is better to overestimate than to underestimate.

The FME NDVI threshold value calibration tool consists of three parts, the first part is the FME NDVI reliability tool as explained in 4.4. The user only uploads the drawn pavement of a small part of the area that needs to be studied. This needs to be done in the way explained in 4.4.

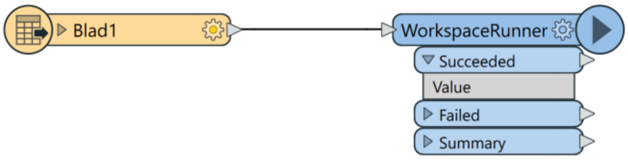

Figure 19; The FME workspace runner used for running the FME NDVI reliability tool for different NDVI threshold values

The second part, namely the Workspace runner, see Figure 19, runs the FME NDVI reliability tool for each NDVI threshold value located in the Excel input file and saves the results of each run underneath each other in one Excel file.

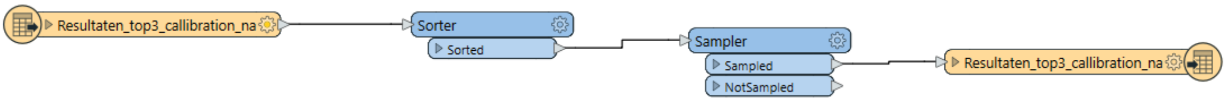

Figure 20; The third part of the calibration tool used to find the top tree NDVI threshold values

After all the runs are completed, the third part can be started, see Figure 20. This part, of the calibration tool, picks the three runs of the calibration with the highest reliability percentage and presents this to the user. This way the user, can pick the most suitable value for the study area considering the amount of over- and underestimation.

5.3. Calibration range

Based on literature it is found that the range for non-vegetation is from 0.199 to -1 (Hashim et al., 2019). During test runs it is noticed that a realistic value is often in the range of 0.1 to -0.1, therefore in this range, the steps will be smaller than in the other ranges. If the optimal input value is outside the range from 0.1 to -0.1 then it will be advised to the user to calibrate more closely around this optimal value with a smaller step size. The ranges and the corresponding step size within the range can be seen in Table 9.

Table 9; Calibration range and step size

Range	Step size
0.199 to 0.101	0.1
0.1 to -0.1	0.02
-0.101 to -1	0.1

5.5 Validation of the FME calibration tool

5.5.1. The validation method

The validation of the FME tool calibration process focuses on the main point of uncertainty, namely the assumption that the optimal value for a small part of the study area is the same as for the whole area. The most optimal method for validating this would be to pick a small part of the study area and the whole study area and run the calibration tool for both areas. This way it could be checked if the NDVI threshold value of the calibration tool is the same for both areas and if the relationship holds. However, this process would take too much time because the impervious surface polygons should be drawn for all the different areas.

As an alternative the calibration tool is used on different areas spread all over the place Raalte. This is because Raalte has 20,000 inhabitants which is the maximum used for one run in the NDVI tool, larger residential areas are split into pieces. The results are compared with each other in the results section, to check if the optimal NDVI threshold value is the same or almost the same for the different locations. If that is the case, it will be assumed that the relationship holds until further proven by additional research. If the optimal NDVI threshold value is not related, then it can be concluded that this calibration method is not suitable.

The calibration is done for four locations inside the city centre of Raalte. The study areas consist of the front and back gardens of the houses at these locations. The following locations are taken into account: Reiger, Baeckenhagen, Tulpenstraat and Zuivelhof. The locations can be seen on the map in Figure 21, including a close-up of the drawn pavement. A detailed picture of each location can be found in Appendix F.

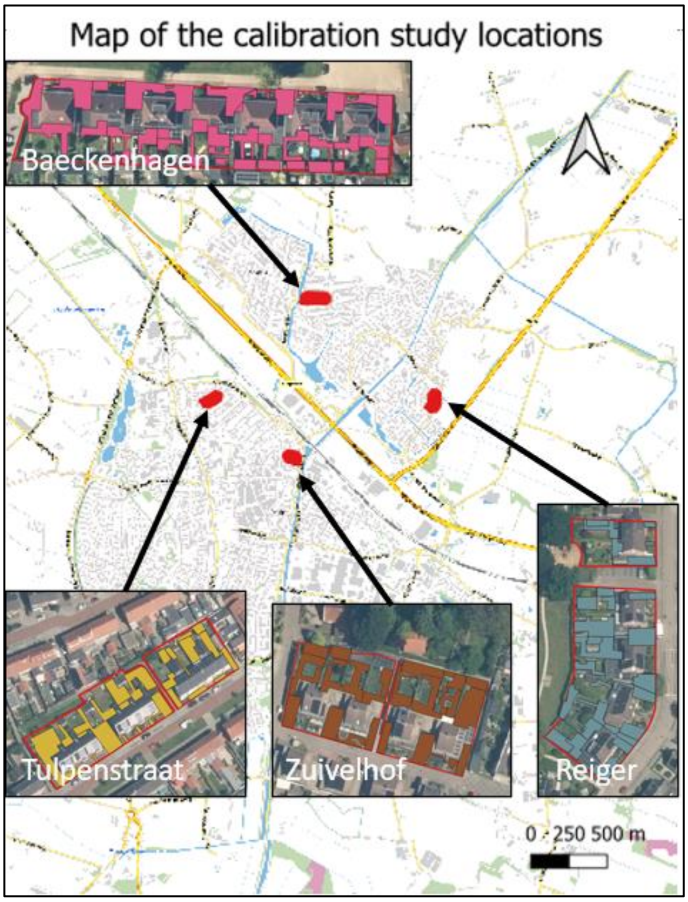

Figure 21; Map of the calibration study locations (red) with a close-up of each location, the coloured polygons are the drawn pavement)

5.5.2. The validation results

The results of the validation of the FME NDVI calibration tool can be seen in Table 10. For each location, the top five with the highest reliability value can be seen with the corresponding NDVI threshold value. The top three that can be seen by the user of the tool are grey in Table 10 and a table with the top ten results of each location can be found in Appendix G.

Table 10; The outcomes of the calibration tool for the different streets in Raalte as part of the validation, the top three shown to the user of the tool can be seen in light grey

	Reliability Percentage	Underestimation Percentage	Overestimation percentage	NDVI_threshold_value (NDVI input value)
Reiger	78.98	11.18	9.84	-0.04
	78.80	12.49	8.71	-0.06
	78.65	10.05	11.30	-0.02
	78.23	13.97	7.80	-0.08
	77.79	8.33	13.88	0.02
Baeckenhagen	81.32	8.62	10.06	-0.08
	81.03	7.64	11.33	-0.06
	80.76	9.99	9.25	-0.1
	80.70	6.59	12.71	-0.04
	80.30	5.60	14.10	-0.02
Tulpenstraat	78.25	10.12	11.64	-0.08
	77.87	12.31	9.82	-0.1
	77.46	6.20	16.34	-0.06
	76.86	5.14	18.00	-0.04
	75.51	4.23	20.26	-0.02
Zuivelhof	77.89	10.81	11.30	-0.02
	77.70	8.27	14.04	0.02
	77.70	12.38	9.92	-0.04
	77.48	7.27	15.25	0.04
	77.11	13.92	8.97	-0.06

In Table 10, it can be seen that not for every location the same NDVI threshold value is optimal for the reliability of the tool. However, it can be seen that the NDVI threshold values are closely located to each other and that the difference between the reliability percentage of number one and number three is a maximum of 0.79 pp. To check what the range is of the NDVI threshold value the 95% confidence interval has been calculated. The outcome is that with 95% certainty, it can be said that for these four streets, the top three NDVI threshold values are located between -0.07342 and -0.03324. So, between -0.08 and -0.02 the confidence will be a bit more than 95%.

The goal of this validation was to check that if you pick one value out of the top three, you can assume the NDVI threshold value will also be good for the other parts of the study area. To check if this is true, all the numbers present in the top three of the locations have been checked for the difference between the reliability corresponding to these values and the reliability of number one of a location. The biggest difference has been found in the case -0.02 is used for the Tulpenstraat, the difference between the optimal of 78.25% (NDVI threshold value -0.08) and 72.94% (NDVI threshold value 0.02) is 5.31 pp which is too big. But for the other locations, the difference is 3.2 pp (Zuivelhof), 2.44 pp (Baeckenhagen) and 1.79 pp (Reiger).

If the same is being done but then for the confidence interval (-0.08 to -0.02). It can be seen that the biggest difference is 2.74 pp at the Tulpenstraat in the case of an NDVI threshold value of -0.02. For the other locations, the difference is 0.75 pp (Reiger), 1.02 pp Baeckenhagen and 1.9 pp Zuivelhof. These values are acceptable and therefore it will be concluded that this calibration method is usable but the user still needs to pay attention if the pavement drawn by the tool makes sense. Since it can still happen that a value is being presented in the top three that is not representative of the whole area like the -0.02 value for the Tulpenstraat.

6. Discussion

This thesis investigates the reliability of the FME NDVI tool used to determine the amount of impervious surface. The results of the FME model research in combination with the literature are influenced by limitations which are addressed in this chapter including an elaboration on the outcomes. The five main points can be seen below.

Firstly, it was found that assessing the influence of monthly precipitation deficit on the drying out of small vegetation as planned was not realistic. After an analysis, it has been determined to replace the monthly precipitation deficit with the amount of precipitation falling in a week before the picture has been taken. The problem, however, was to obtain infrared pictures with a high resolution in combination with a date when the picture has been taken. In the end, only one picture per year was available and this resulted in the fact that there was a substantial difference between the months the picture has been taken year on year. This has affected the results of the analysis since the temperature for example in February is completely different than in June. Therefore, more information is needed relating to the influence of temperature and for a more reliable study infrared pictures with dates closer to each other are needed.

Secondly, in the reliability part added to the tool, the tool presents what percentage is overestimated and underestimated. It can be the case that the total amount over- and underestimation is almost equal resulting in the fact that the total sum of pavement is the same as is the case in real life. Think about a piece removed from a pie and added to the outer area of the pie. The total amount of pie stays the same, it is just located at a different place. So, if the user only needs the total sum of impervious surfaces, then even if the reliability is low the results can still be correct. This fact should be a point of attention to the user.

Thirdly, it was difficult to obtain reliable literature related to environmental factors influencing the NDVI tool used to determine impervious surfaces. One of the environmental factors that has been chosen was the soil type, however, the results show that it cannot be said that there is a relation between the soil type and the reliability of the NDVI tool. This could be because the top layer of the soil at most locations is sand and therefore the reflection of the soil is the same. But more research is needed to prove this.

Fourth, a factor that influenced the reliability numbers obtained while studying the influence of soil type and leaves covering the impervious surface is the drawing of the impervious surface. This has been done in Qgis using the PDOK pictures, one of the problems was the angle of the plane relative to the buildings. This led to the pavement not being drawn correctly, see Figure 22 on the next page, where the pavement is drawn inside the building. This is important since the outlines of the buildings are being cut away in the NDVI tool using the BGT database. So, if the drawn pavement is overlapping with the outline of the building, then this is seen by the tool as a fault. This also happens the other way around, where the tools pavement is connected to the outline of the building while the drawn pavement has a gap between the outline of the building and the pavement. Resulting in lower reliability of the tool compared to the real-life situation. An additional fault that happened here, is that not all the buildings are included in the BGT database, while this was assumed while drawing the real-life pavement. This resulted, in the tool estimating that something was paved while in real life it was a building. So, this also lowered the reliability of the tool.

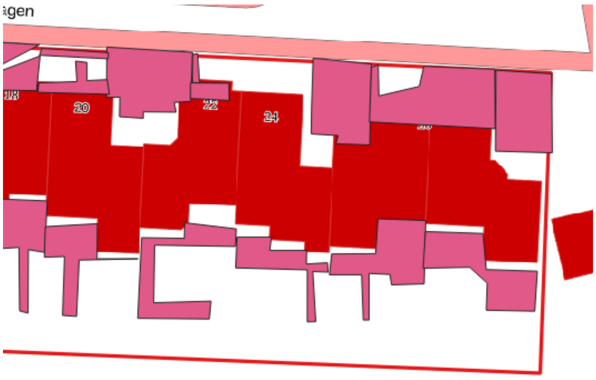

Figure 22; The angle of the camera influences the reliability of the tool (red=buildings, pink=pavement)

Lastly, the validation of the calibration tool has only been done for Raalte in Overijssel. To be able to conclude with certainty that it is a suitable addition to the use of the FME NDVI tool this validation should have been done to more places.

7. Conclusion and recommendations

7.1. Conclusion

The objective of this research was to make the output of the NDVI tool more reliable in private areas by finding the environmental factors that impact the reliability of the tool and by determining the most suitable NDVI threshold value for the tool in combination with the amount of precipitation deficit before the NDVI value is calculated each year in one sample area for each environmental factor being addressed.

Question 1: What is the impact of precipitation deficit on the colour differences of small vegetation in the infrared picture?

No clear relationship between monthly precipitation deficit and the drying out of small vegetation has been found in the literature. A relationship between the different precipitation classes and the colour differences of small vegetation has been found. The relationship says that the low precipitation class has the highest red and infrared values, followed by the high precipitation class and the medium precipitation class has the lowest values. This relationship does not seem to be realistic. Because there is a big difference between the dates that the infrared pictures have been taken for the different precipitation classes.

Question 2: In which type of environment can the reliability of the NDVI tool be optimized?

The following environmental factors have been addressed in this research, namely soil type, presence of bare soil, tree crowns, water bodies and shadows of buildings. Out of these five, based on the literature and the fact that the study areas are private gardens, it has been chosen to further assess the effect of soil type and tree crowns on reliability. The soil types human podzol, calcareous sandy soil and clay have been taken into account. Based on the results, no clear relationships have been found between different types of soil and the reliability of the tool.

A clear relationship has been found between the reliability of the tool and the presence of tree crowns. The reliability underneath the tree crowns drops in case leaves are present on the trees compared to no leaves on the trees for the same location. Furthermore, the influence of leaves on tree crowns on reliability is relatively high in the case of terraced houses compared to detached houses. So, the reliability of the tool can be optimized in areas with tree crowns covering the pavement by taking an infrared picture where no leaves are present on the trees.

Question 3: In what way can the use of the tool be improved concerning the NDVI threshold value in the specific environments found in the questions above?

Since in earlier research questions no clear relationship between precipitation, soil type and the NDVI has been found, it has been determined to not address these factors in question 3. There is a relationship between tree crowns and the reliability of the tool but here the solution is not to focus on the NDVI threshold value. As a result, it has been decided to improve the tool by developing a quick FME calibration tool for the NDVI threshold value of a certain study area. This is because the optimal NDVI threshold value depends on the study area. After validation, it has been concluded that this tool is a good method to determine the optimal NDVI threshold value and that it can be used to improve the reliability of the tool. After this calibration has been done, the user should still check if the results are logical.

General conclusion

So, there is no optimal NDVI threshold value to get the highest reliability in combination with precipitation deficit, soil type and tree crowns. However, leaves on the trees negatively affect the reliability of the tool. Therefore, for a study area with a lot of trees, it is better to pick a picture without leaves on the trees to reach higher reliability. Furthermore, the calibration tool can help with getting the optimal NDVI threshold value for a certain study location resulting in optimized reliability.

7.2. Recommendations

Based on the observations done during this research, five recommendations can be described.

First, I do recommend further looking into the effect of precipitation on the reliability of the FME NDVI tool used to determine the amount of impervious surface. To properly do this, the influence of other factors apart from the precipitation should be limited. This can be partly done by making sure that the pictures used in this study are taken at the same time of the year. Furthermore, there should be looked closer into the relationship between precipitation deficit and the drying out of the grass. What is necessary for grass to dry out and how can these factors be measured?

The second recommendation is to study the relationship between temperature and the reliability of the NDVI tool. Since it has been found in the literature that the correlation between temperature and monthly NDVI value is high. This could mean that a higher or lower temperature can severely influence the NDVI values of the study area and this way it could influence the reliability of the NDVI tool. So, a study should be done to check if the time of the year that the pictures are being taken influences the reliability of the NDVI tool.

This also results in the third recommendation, which is that the tool should be less depending on the one picture obtained each year by PDOK. It is advised to look closer into alternative sources for pictures such as satellite infrared pictures, which are taken every day.

Fourth, while using the FME NDVI tool it is advised that the user pays attention to the presents of trees and if these trees have leaves or not on the infrared picture. If there are leaves present on the trees then it is advised to the user to switch to a picture where no leaves are present. Since this will improve the reliability of the outcomes of the tool close to the tree.

Fifth, it is advised for the users of the FME NDVI tool to use the calibration tool developed in this study. This way, the NDVI threshold value of the tool can be optimized for the study area. To use the NDVI calibration tool, the user needs to check if the pavement drawn is corresponding with the outline of the buildings in the BGT. The user also needs to check if all the buildings present in the study area are drawn in the BGT database and if this is not the case then the user should draw the building as an impervious surface.

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9. Appendices

9.1. Appendix A – Explanation of the FME NDVI tool

Confidential information

9.2. Appendix B – Explanation mean infrared and red calculator FME Tool

Confidential information

Confidential information

9.3. Appendix C – Information on the study areas for the influence of precipitation on small vegetation

In this appendix, more information on the study areas of Hardenberg, Hengelo and Berkum can be found and the information related to picture dates and precipitation values. These study areas are used to answer the question related to the influence of weekly precipitation on the infrared and red values.

Hardenberg

The study location is in the city centre of Hardenberg, top right of Figure 27 and the KNMI measurement station is the yellow dot in the bottom left corner. The distance between the two locations is 6 km.

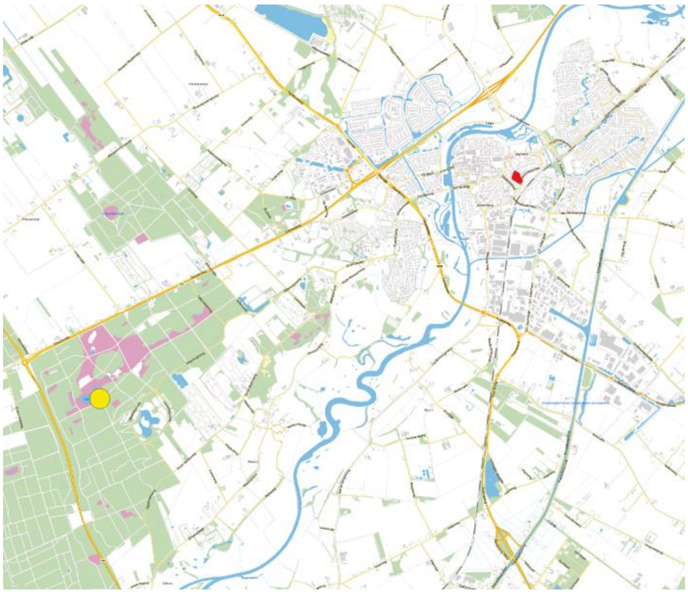

Figure 27; KNMI measurement station (yellow dot) and the study area (red) in Hardenberg

For the city of Hardenberg, the gardens of the even-numbered houses at the Beatrixstraat 2-24 and the uneven-numbered houses at the Irenenstraat 1-11 will be considered. This can be seen in detail in Figure 28.

Figure 28; The research area (red) of Hardenberg

Hengelo

The study location is located in the city centre of Hengelo, left of the centre of Figure 29 and the KNMI measurement station is the yellow dot at the left side of the figure. The distance between the two locations is roughly 1.3 km.

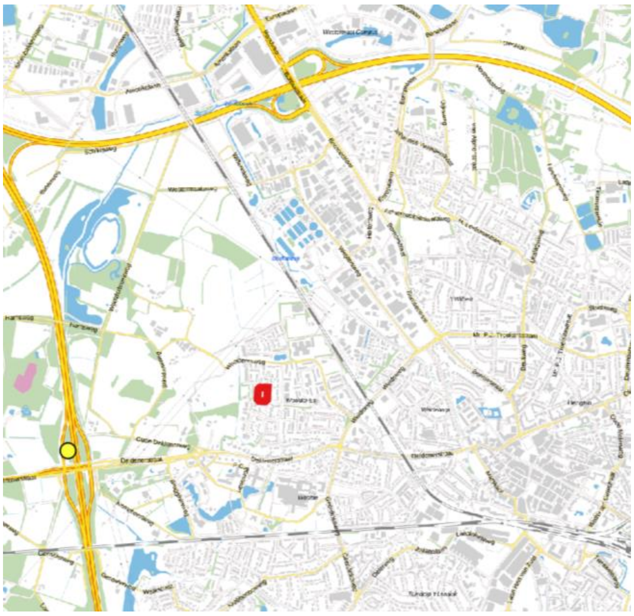

Figure 29; KNMI measurement station (yellow dot) and the study area (red) in Hengelo

For the city of Hengelo, the gardens of the even-numbered houses at the Bantingstraat 2-16 and uneven-numbered houses at the Pasteursstraat 35-49 will be taken into account. The research area can be seen more closely in Figure 30.

Figure 30; The research area (red) of Hengelo

The aerial picture date and weekly precipitation values before the picture has been taken can be found in Table 11.

Table 11; The aerial photo date for the different years and the corresponding amount of precipitation (mm) in Hengelo

Aerial Photo Date	Amount of Precipitation (mm)
05-04-2023	33 (photo is not available at the moment of conducting the study)
16-06-2022	15.4
06-04-2020	0
15-02-2019	30.3
19-04-2018	5.4
11-05-2017	6.5
The 2016 date is unknown	-

Berkum (measurement station Zwolle)

The study location is in the centre of Berkum, top right of Figure 31 and the KNMI measurement station is the yellow dot in the middle of the figure. The distance between the two locations is roughly 1 km.

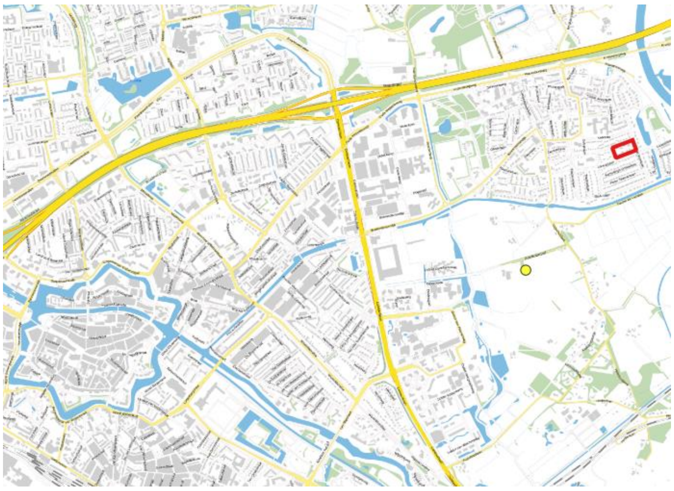

Figure 31; KNMI measurement station (yellow dot) and the study area (red) in Berkum

For the village of Berkum (close to KNMI measurement station Zwolle), the gardens of the uneven-numbered houses at Lorentzlaan 27-35, Hugo de Vrieslaan 11-15 and the even-numbered houses at Boerhavelaan 32-40 will be taken into account. See Figure 32, for a more detailed picture of the study area.

Figure 32; The research area (red) of Berkum

The aerial picture date and weekly precipitation values before the picture has been taken can be found in Table 12.

Table 12; The aerial photo date for the different years and the corresponding amount of precipitation (mm) in Berkum

Aerial Photo Date	Amount of Precipitation (mm)
01-03-2023	6.9
22-06-2022	0.6
15-04-2020	0
15-02-2019	22.6
20-04-2018	7.5
27-03-2017	5.3
16-03-2016	0.3

9.4. Appendix D – Information on the study areas for the influence of soil type on the reliability of the FME NDVI tool

In this appendix, more information on the study locations used for determining the influence of soil type on the reliability of the tool can be found.

Staphorst

The place Staphorst is used as the location for human podzol soils. The specific type present in the areas drawn in Figure 34 is Field podzol soil (Research & Nederland, 2023). Using the BRO REGIS II database the drill sample with Identification number B21F0398 (*Basisregistratie Ondergrond Regis II* 2023), it can be seen in Figure 33, that the soil from 0-4m1 completely consists of sand.

Figure 34; The drill sample location (purple dot) the study area (red) and the human podzol classification (pink area) (Basisregistratie Ondergrond Regis II 2023; Research & Nederland, 2023)

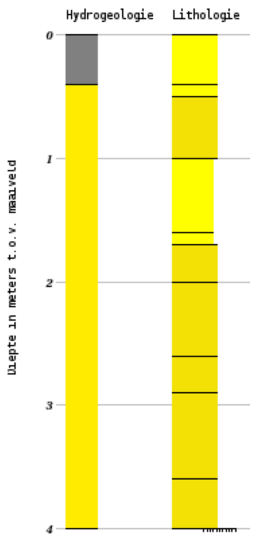

Figure 33; The soil sample of Staphorst soil type can be seen in lithologie (yellow=sand) and hydrogeologie focusses on groundwater (Basisregistratie Ondergrond Regis II 2023)

The areas are located at Weidelanden and Hoenderweg, close to the drill sample location. The areas can be seen in more detail in Figure 35.

Figure 35; The study locations (red) for the human podzol soil in Staphorst

Haaksbergen

The city of Haaksbergen is used as the location for calcareous sandy soils. The specific type present in the areas drawn is in Dutch called “Beekeerdgronden”, see the green area in Figure 36 (Research & Nederland, 2023). Using the BRO REGIS II database the drill sample with Identification number B34E0109 (*Basisregistratie Ondergrond Regis II* 2023), it can be seen in Figure 37 that the topsoil is sand (0-3.1m1), loam(3.1-4.8m1) followed by clay (4.8-5m1). The drill point is not located within the coloured soil area since the urban areas are often not given a certain soil type in the soil map of Overijssel. However the drill point is located close to the research area, see Figure 36.

Figure 36; The drill sample location (green dot) the study area (red) and calcareous sandy soil (green area) (Basisregistratie Ondergrond Regis II 2023; Research & Nederland, 2023)

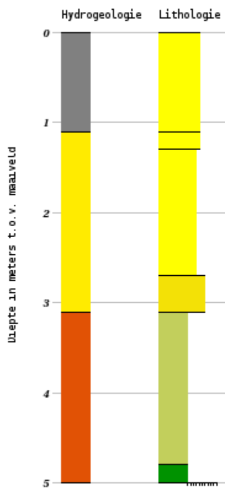

Figure 37; The drill sample of Haaksbergen the soil type can be seen in lithologie (yellow=sand, olive=loam and green=clay) and hydrogeologie focuses on groundwater (Basisregistratie Ondergrond Regis II 2023)

The first area is located at Korenbloem, Leeuwebek, Gentiaan and goudsbloem and the second area is Gentiaan and Klaproos. The areas can be seen in Figure 38.

Figure 38; The study locations (red) for the calcareous soil in Haaksbergen

Zwolle (Stadshagen)

The city of Zwolle is used for Clay. The specific type present in this city depends on the location, but the research location is located in the North West part of the neighbourhood of Stadshagen where the soil type is River Clay (Research & Nederland, 2023). This soil type can be seen in grey in Figure 39 Looking closer into the BRO REGIS II database the drill sample (Figure 40) with Identification number B21D0123 (*Basisregistratie Ondergrond Regis II* 2023), it can be seen that the topsoil is sand (0-0.4m1), clay (0.4-0.6m1) followed by peat (0.6-0.9m1).

Figure 39; The drill sample location (green dot) the study area (red) and river clay (grey area) (Basisregistratie Ondergrond Regis II 2023; Research & Nederland, 2023)

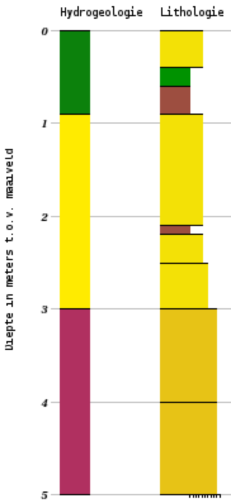

Figure 40; The drill sample of Stadshagen the soil type can be seen in lithologie (yellow=sand, green=clay and purple=peat) and hydrogeologie focuses on groundwater (Basisregistratie Ondergrond Regis II 2023)

The study area is located at the Cleynederstraat, close to the drill sample location and can be seen in Figure 41.

Figure 41; The study location (red) for the Clay soil of Stadshagen

9.5. Appendix E – Information on the study areas for the influence of tree crowns on the reliability of the FME NDVI tool

In this appendix more information on the study locations in Nijverdal, Zwolle, Raalte, Luttenberg and Oldenzaal used for determining the influence of tree covers on the reliability can be found.

Nijverdal

The first location that is used is the uneven-numbered houses at the Vondelstraat from 41 up to and including 85. The houses are mostly terraced. The study area can be seen in close detail in the case of leaves and no leaves in Figure 42 and Figure 43 the location of the study area within Nijverdal can be seen.

Figure 42; The study area (red) at the Vondelstraat in 2018 without leaves on the trees and in 2020 with leaves

Figure 43; The study location (red stripe) at the bottom of Nijverdal

Zwolle

The location to be used is the Wipstrikkerallee 95 and the uneven-numbered houses from 109 up to and including 145. The houses are mostly detached. The study area can be seen in close detail in Figure 44 and in Figure 45 the location of the study area within Zwolle can be seen.

Figure 44; The study area (red) at the Wipstrikkerallee

Figure 45; The study location (red stripe) in Zwolle

Raalte

The location to be used is the even-numbered houses at the Westdorplaan from 90 up to and including 110. The houses are mostly terraced. The study area can be seen in close detail in Figure 46 and in Figure 47 the location of the study area within Raalte can be seen.

Figure 46; The study area (red) at the Westdorplaan

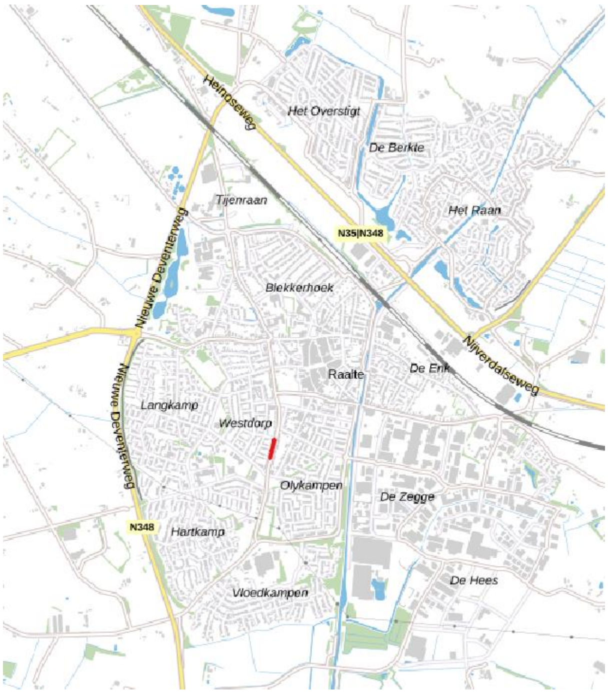

Figure 47; The study location (red stripe) in Raalte

Luttenberg

The next location to be used is the uneven-numbered houses at the Lemelerweg from 3 up to and including 23. The houses are mostly detached. The study area can be seen in close detail in Figure 48 and in Figure 49 the location of the study area within Luttenberg can be seen.

Figure 48; The study area (red) at the Lemelerweg

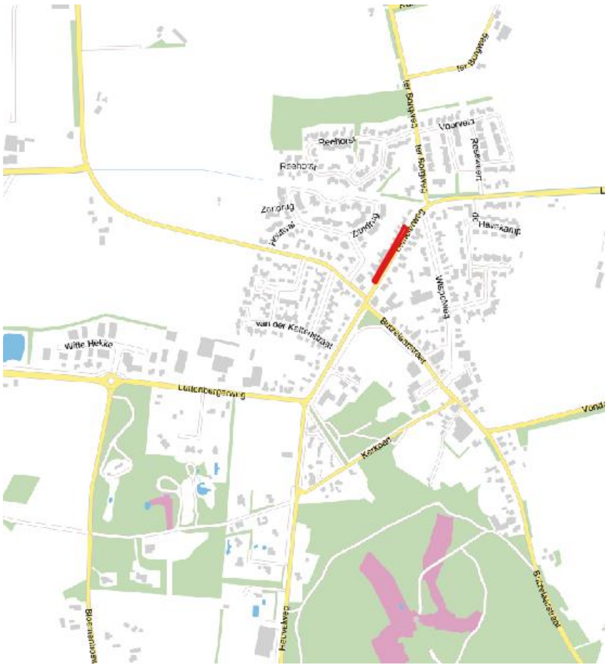

Figure 49; The study area (red) in Luttenberg

Oldenzaal

Figure 50; The study area (red) at the Dr. Nolenstraat

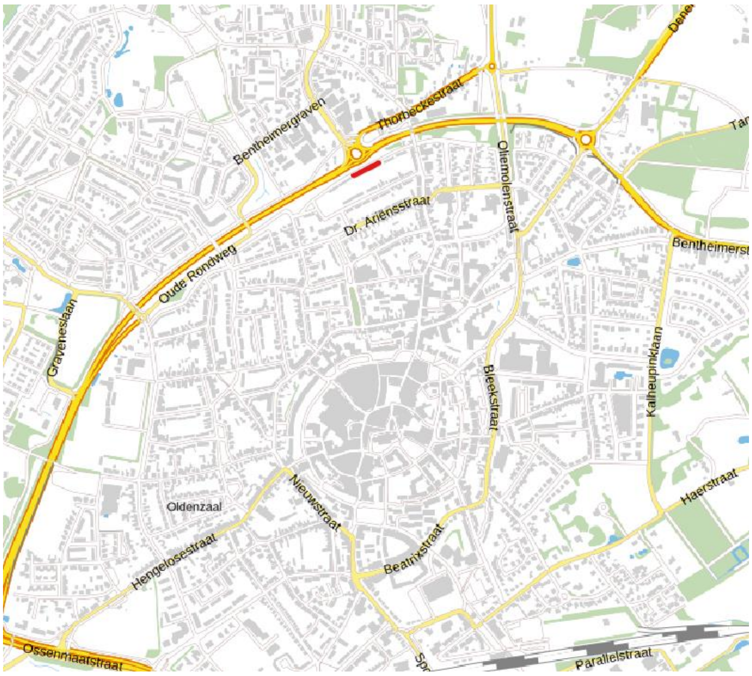

Figure 51; The study area (red) in Oldenzaal

The next location to be used is the uneven-numbered houses at the Dr Nolenstraat from 25 up to and including 49. The houses are mostly terraced. The study area can be seen in close detail in Figure 50 and in Figure 51 the location of the study area within Oldenzaal can be seen.

9.6. Appendix F – The validation locations of the FME NDVI input calibration tool

In this appendix more information on the study locations used for the validation of the FME NDVI calibration tool. Reiger, Baeckenhagen, Tulpenstraat and Zuivelhof. Notice, that the sheds behind the houses are drawn as pavement since they are not included in the BGT.

Reiger

The study area of the Reiger with the drawn pavement can be seen in Figure 52.

Figure 52; The study area (red) Reiger with the drawn pavement (grey polygons)

Baeckenhagen

The study area of Baeckenhagen with the drawn pavement can be seen in Figure 53.

Figure 53; The study area (red) Baeckenhagen with the drawn pavement

Tulpenstraat

The study area of the Tulpenstraat with the drawn pavement can be seen in Figure 54.

Figure 54; The study area (red) Tulpenstraat with the drawn pavement

Zuivelhof

The study area of Zuivelhof with the drawn pavement can be seen in Figure 55.

Figure 55; The study area (red) Zuivelhof with the drawn pavement

9.7. Appendix G – Top 10 of the calibration results for each location

In this appendix, the calibration top 10 with the corresponding NDVI value can be seen.

Table 13; The top 10 of the calibration for each location, the top three are shown to the user (grey)

	Reliability Percentage	Underestimation Percentage	Overestimation percentage	NDVI_threshold_value
Reiger	78.98	11.18	9.84	-0.04
	78.80	12.49	8.71	-0.06
	78.65	10.05	11.30	-0.02
	78.23	13.97	7.80	-0.08
	77.79	8.33	13.88	0.02
	77.38	7.60	15.02	0.04
	77.19	15.88	6.93	-0.10
	76.42	6.94	16.64	0.06
	75.29	6.33	18.38	0.08
	73.67	5.60	20.73	0.10
Baeckenhagen	81.32	8.62	10.06	-0.08
	81.03	7.64	11.33	-0.06
	80.76	9.99	9.25	-0.10
	80.70	6.59	12.71	-0.04
	80.30	5.60	14.10	-0.02
	78.88	4.28	16.83	0.02
	77.73	3.70	18.57	0.04
	76.93	3.18	19.89	0.06
	76.23	2.59	21.18	0.08
	75.26	2.02	22.72	0.10
Tulpenstraat	78.25	10.12	11.64	-0.08
	77.87	12.31	9.82	-0.10
	77.46	6.20	16.34	-0.06
	76.86	5.14	18.00	-0.04
	75.51	4.23	20.26	-0.02
	72.94	2.88	24.18	0.02
	71.39	2.47	26.15	0.04
	69.71	2.00	28.30	0.06
	68.55	27.82	3.63	-0.20
	68.23	1.76	30.01	0.10
Zuivelhof	77.89	10.81	11.30	-0.02
	77.70	8.27	14.04	0.02
	77.70	12.38	9.92	-0.04
	77.48	7.27	15.25	0.04
	77.11	13.92	8.97	-0.06
	77.05	6.43	16.52	0.06
	76.48	5.66	17.86	0.08
	75.99	15.92	8.08	-0.08
	75.63	4.89	19.48	0.10
	74.69	17.97	7.34	-0.10