Remote Sensing of Glyphosate usage over agriculture areas around Enschede

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Abstract

The increasing concern over the use of Glyphosate-based herbicides (GBH) in agriculture, among with the possibilities that EU can ban the use of GBH from 2024, has led to the need for a methodology to supervise its usage. The current progress of satellite imaging technology, particularly in the European Union's Copernicus program, has provided an opportunity for remote sensing techniques for vegetation monitoring, which can be utilized to supervise GBH usage. In this study, we presented a methodology based on the normalized difference vegetation index (NDVI) calculated from satellite images, which can detect changes in vegetation color over time and indicate the use of GBH. We conducted experiments on three different study areas, two in the Netherlands and one in Germany. We obtained promising results in detecting changes in vegetation color due to GBH usage: Our results showed that NDVI could be a valuable tool for monitoring GBH, especially when used with ground-based surveys to verify the findings.

Keywords: Geographical Information Systems, Remote Sensing, Copernicus Satellite, Glyphosate.

1 Introduction

For decades, humans have used herbicides in the agriculture sector to control unwanted plants and increase crop productivity, and one of the most widely used herbicides currently is Glyphosate. Glyphosate specializes in broadleaf and grass that compete with crops, although it is non-selective and will kill most plants, except for genetically-modified plants. Moreover, together with other herbicides and pesticides, the concern on Glyphosate-based herbicides (GBH)'s effect on human and animal (especially insects) health [10], to soil [6], and to the ecosystem is growing, partially due to our limited understanding on their long-term risks. In the European Union, GBH is approved for agriculture use until the end of 2023 with a possible renewal[1], however, there are growing calls on banning the substances, with Germany leading the charge by phasing out GBH gradually until a complete ban starting from 2024 [1]. Therefore, there is an increasing need for a methodology that can supervise the usage of Glyphosate for future enforcement should an EU-wide ban take place.

The current progress of satellite imaging technology, especially by the European Union's Copernicus program, has seen the rise in the application of remote sensing techniques, such as for vegetation traits [11], soil moisture [13], and vegetation function [3]. The current development of remote sensing makes it a perfect method for supervising the use of Glyphosate. Since GBH-based herbicides can kill most plants, the field on which GBH is applied can be characterized by its yellow-orange color, with a hint of green.

This paper will be structured as below: Section 2 will discuss other related work to this topic, while section 3 will discuss different methods and tools we used to obtain, process, and visualize the data. Our findings will be presented in section 4, followed by a comprehensive discussion in section 5. Finally, we will conclude our study in section 6 and suggest areas for future research in section 7.

2 Related Work

Currently, there are few works on the remote sensing of GBH due to the novelty nature of the topic: Pause et al.[9] presented a proof-of-principle approach that changes in the field using GBH can be detected from satellite images, with promising results - the only resource for GBH satellite remote sensing. Eide et al. [2] performed UAV sensing of Glyphosate resistance in weeds, while Henry et al. [5] performed remote sensing for herbicide drift on crops.

On the topic of remote sensing of Normalized difference vegetation index (NDVI), there are also limited resources available. Evans et al. [13] used a machine learning model trained on satellite NDVI images to predict future NDVI values for periods without satellite data. In contrast, Matongera et al. [7] completed a review on the progress and challenges of monitoring land surfaces (including metrics like NDVI) by satellite data.

[1] https://food.ec.europa.eu/plants/pesticides/approval-active-substances/renewal-approval/glyphosate_en

3 Methodology

3.1 Vegetation Index

Since a yellow-orange color characterizes GBH-affected vegetation, satellite data can visualize if a field is treated. Vegetation indices are calculated from satellite images on multiple periods. The change in these vegetation indices over multiple images indicates vegetation color developments over time. These vegetation indices are calculated with operations on spectral bands of the image data. In our research, we focus on the normalized difference vegetation index (NDVI).

The normalized difference vegetation index characterizes the density of vegetation. Regions with photosynthesis activity absorb the visible red spectrum and reflect the near-infrared spectrum. In unhealthy crops, less of the visible red spectrum and less of the near infra-red spectrum are absorbed. The ratio of the spectra visualizes the chlorophyllic activity [8].

$$NDVI = \frac{NIR - RED}{(NIR + RED)} \tag{1}$$

3.2 Study Site

In our study, three different study areas have been chosen, with varying location and land area.

3.2.1 Kitze, Germany. The Kitze area is one of the area studied by Pause et al. [9]. It situated close to Poppenwind, in the municipality of Auengrund, district of Hildburghausen, Thuringia, Germany. Kitze is a relatively small area, however with a considerably high difference in NDVI value before and after applying GBH, and with results that already been verified, it helps us in exploring and understanding the data, as well as establish a good start for later analysis of Enschede farmlands. Other regions mentioned by Pause et al. has also been studied as well, such as Kas und Brot and Lange. The visualization of the study site can be seen in figure 7.

3.2.2 Usseler Es, Enschede, Netherlands. The Usseler Es study area is located in the southwest region of Enschede, bordered by the Usselerondweg, the A35, and the N18 highway, as defined in figure 5. Since GroenLinks had already observed the uses of GBH-based herbicide in their news article on May 2019 [12], it is a good study area to observe the impact of Glyphosate on satellite images and vegetation indices. On the Usseler Es study area, we plot the changes in NDVI scores between each image and select the area with the most change (from the 1st of March 2019 until the 30th of June 2019). According to Google StreetView data in the neighboring years (ranging from 2015 to 2022), these sites are used to plant maize. Therefore, it can be assumed that in the Spring and Summer of 2019, the crops on the sites in Usseler Es are also maize.

3.2.3 Southeast farmland, Enschede, Netherlands. The question arose if glyphosate could be detected in other areas. Even though there is uncertainty that herbicide use is applied, it could provide areas for further experimentation and even selective on-site investigation. Enschede first was investigated with the Corine land cover dataset to select a broad swab of agricultural land. With this satellite image, we identified an expansive agricultural area to the southeast of Enschede (see figure 8 in "Study Sites"). Since glyphosate is used from March to May, this region was analyzed. By subtracting the NDVI scores over time, two plots of farmland saw decreasing NDVI scores compared to other plots in the region that turned green. Upon further investigation in Google Earth, these were determined to be corn fields in 2021. We assume that in 2019 it was corn as well. Under these assumptions, These two areas of interest, named "Kersdijk" and "Berktepaalweg" (see figure 10 and 11 in "Study Sites") are investigated in more detail at the same timeframe as the Usselerondweg site of interest since that is assumed to be corn as well.

3.3 Satellite Image Data gathering and processing

3.3.1 Copernicus Sentinel-2 Harmonized data. In our study, we applied the Corpenicus Sentinel-2 Harmonized (S2-harmonized) Satellite data acquired via Google Earth Engine (GEE) [4]. S2-harmonized data is part of the European Commission's Earth Observation/ Space program, which haves sub-pixel multispectral and multitemporal registration accuracy. After the raw images are collected, the NDVI score is calculated using equation 1. The image is visualized in two ways: As a standalone image, where a layer of NDVI-score of the field is overlaid on the map, and as a "difference in NDVI score image ($NDVI_{diff}$)":

$$NDVI_{diff} = |NDVI_i - NDVI_{i+1}| \tag{2}$$

With $NDVI_i$ the NDVI score of the current image, and $NDVI_{i+1}$ the NDVI score of the next image. We then visualize those changes, similar to how a standalone image is visualized. Afterward, the region with the most change in NDVI score got separated and downloaded. Saved images per region over a specific period are then visualized using a bin plot in Python to display the shift in NDVI score for each pixel of an image.

3.3.2 Corine data. The CORINE (Coordination of Information on the Environment) program is an initiative of the European Environment Agency (EEA) that provides land cover and land use information across Europe [2]. The data is derived from satellite imagery and is classified into a hierarchical system of classes, ranging from broad land cover categories such as forests and agriculture to more specific classes such as vineyards and golf courses. The CORINE data is widely used for various applications, including environmental monitoring, land management, and policy planning. In this research, we use CORINE to segment a region (Enschede southeast) that contains majority farmlands, for further analysis of Glyphosate usage.

[2] https://land.copernicus.eu/pan-european/corine-land-cover

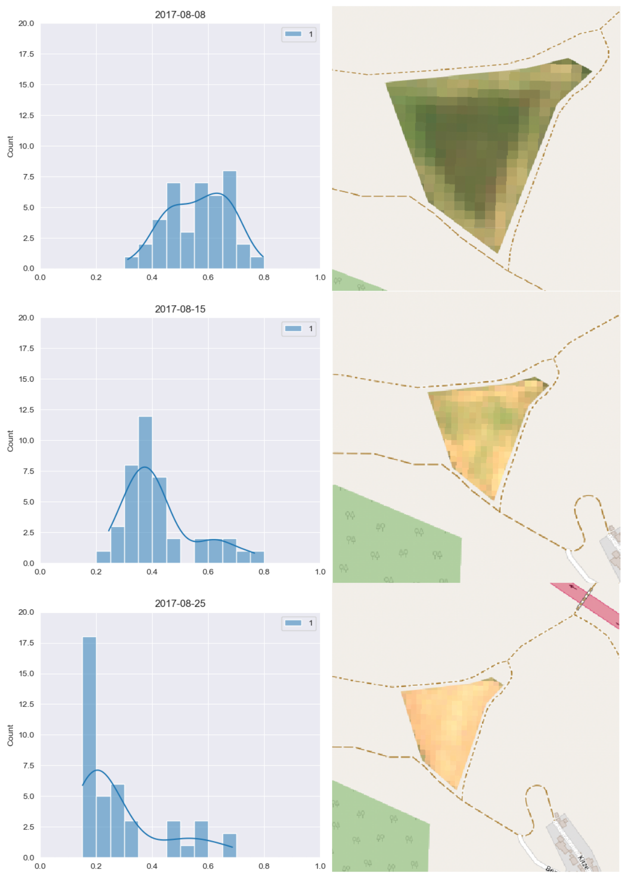

Figure 1. NDVI value shifting over time of Kitze site, with correspoding satellite image.

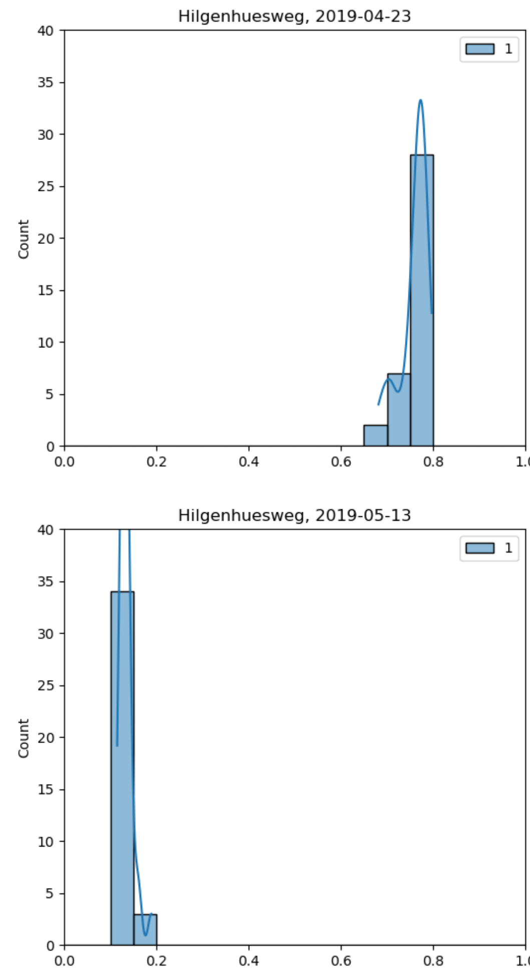

Figure 2. NDVI value shifting over time of Hilgenhuesweg site.

4 Results

4.1 Kitze site

The analysis result for the Kitze site is shown in figure 1. The top image was taken on 08/08/2017, one day before GBH was applied according to Pause et al. [9] - where there were plenty of greens, and the NDVI score was distributed evenly. However, one to two weeks after applying (shown in the second and third image), NDVI distribution changes drastically. Especially after two weeks, all greeneries were gone, indicating how NDVI can measure the impact of GBH treatment.

4.2 Usseler Es region

Using our method, six areas in which NDVI changes were significant have been identified, visualized in figure 6 below. The results for the Usseler study site, with five smaller focus areas, are shown in figure 3, with results for the Hilgenhuesweg area shown in figure 2. Overall, there is a large shift in NDVI values - from the beginning, when the images are collected, until the end, for all study sites. While most study sites see a gradual decrease, two study sites have a different pattern: Hilgenhuesweg and Ruilverkavelingsweg-2. These two sites had an abrupt decrease over 2-3 weeks - no pixels in the image with an NDVI value larger than 0.2 - and mostly stayed in the 0.1 to 0.15.

4.3 Southeast Enschede farmland

Figure 4 depicts the NDVI trends of both the Kersdijk and Bertepaalweg sites over time. Similarly to the Usseler site, both sites exhibit a shift in NDVI values from mid-May to early June, followed by a gradual increase in NDVI values. Kersdijk experienced a sharp decline from April 8 to April 18, while Bertepaalweg remains relatively stable. However, from April 18 to May 13, Kersdijk experienced a further significant decrease, similar to the one observed earlier, while Bertepaalweg showed a comparable decline. After May 13, both sites exhibit a slow increase in NDVI scores. Interestingly, the NDVI scores become more scattered once the major decline occurs.

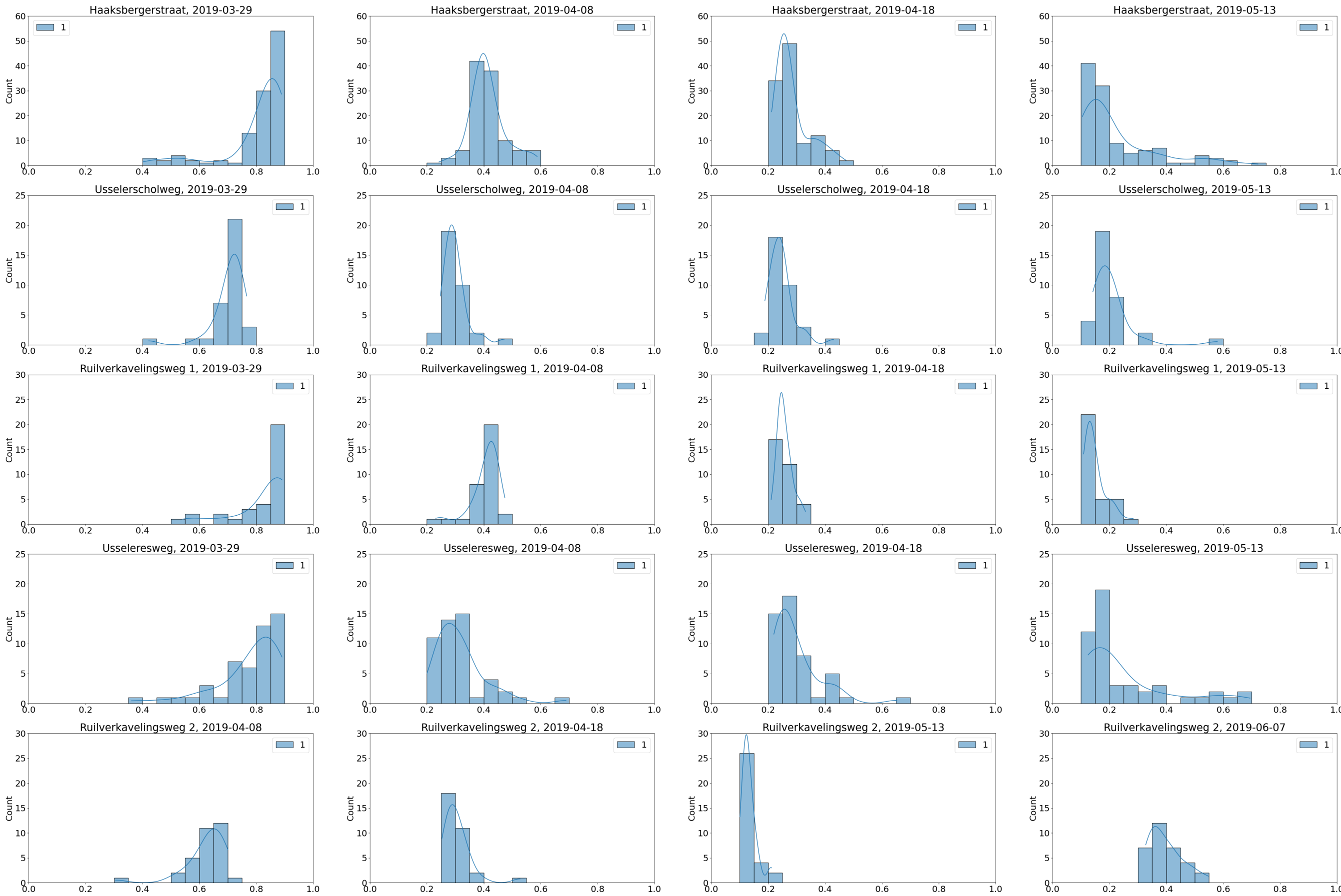

Figure 3. From top to bottom: NDVI value shifting over time of sites Haaksbergerstraat, Usselerscholweg, Ruilverkavelingsweg 1, Usseleresweg, and Ruilverkavelingsweg 2.

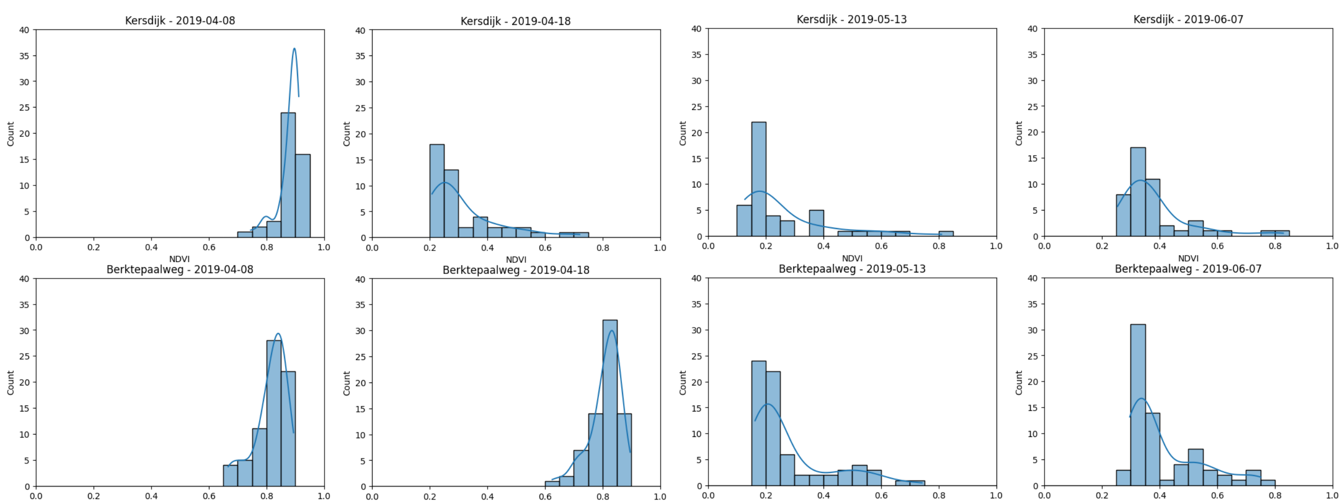

Figure 4. NDVI value shifting over time of sites "Kersdijk" and "Berktepaalweg"

5 Discussion

The study presented in this paper aimed to investigate the impact of glyphosate-based herbicides (GBH) on vegetation indices derived from satellite imagery. To achieve this, we focused on the normalized difference vegetation index (NDVI), which characterizes vegetation density. The NDVI was calculated for multiple periods in three different study areas: Kitze, Germany, Usseler Es and Southeast farmland in Enschede, Netherlands. The results showed a considerable difference in NDVI values before and after applying GBH, particularly in the Kitze area, which was already studied by Pause et al. [9]. This provided a good starting point for further analysis of the Enschede farmlands. The study also revealed six areas with the most significant changes in NDVI scores in the Usseler Es study area and two in the Enschede Southeast area. Further investigation using Google Earth confirmed that these areas were used to plant maize, suggesting that glyphosate's impact on vegetation indices can be detected through satellite imagery. This finding highlights the potential of satellite imagery in detecting GBH use in areas where herbicide application is uncertain, thus paving the way for further experimentation and on-site investigation.

However, while satellite imagery can provide valuable information about agricultural practices, such as detecting herbicide applications, it still has limitations regarding accuracy and resolution. For example, satellite imagery may not be able to detect glyphosate application at the individual plant level or differentiate between different types of herbicides. Changes in NDVI score could also be due to another external factor, such as drought. Furthermore, it is possible that glyphosate was applied to the Enschede field but was not captured in the satellite imagery due to various factors such as weather conditions, the timing of the imagery, or the application method used. Therefore, while the lack of glyphosate detection in satellite imagery is suggestive, it is inconclusive evidence that glyphosate was not used in the field. Overall, this highlights the importance of incorporating multiple sources of data and considering the limitations of each when making conclusions about agricultural practices. In this case, gathering additional data would be beneficial to corroborate or refute the findings from the satellite imagery.

6 Conclusion

This research presented a method to identify the usage of GBH-based herbicide based on satellite image. Based on our results, we can conclude that NDVI is a good indicator of whether Glyphosate has been applied at a field - after GBH treatment from one to two weeks, NDVI score decreased drastically. Our method could be used for pre-screening of daily satellite image and detect whether a region/field has a difference in NDVI over a course of a week. In case of a glyphosate ban and inspections are carried out regularly, these informations would be useful to narrow down "suspected" regions.

7 Future Research

Future research could be focused on automating the workflow, from determining the changes of NDVI over a certain period to using a clustering algorithm to segment a suspected region automatically. Machine learning could also be used to classify if a region has glyphosate applied or not automatically. However, this method requires more study into how vegetation indices correlate and causate changes by GBH.

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Appendix A Study Sites

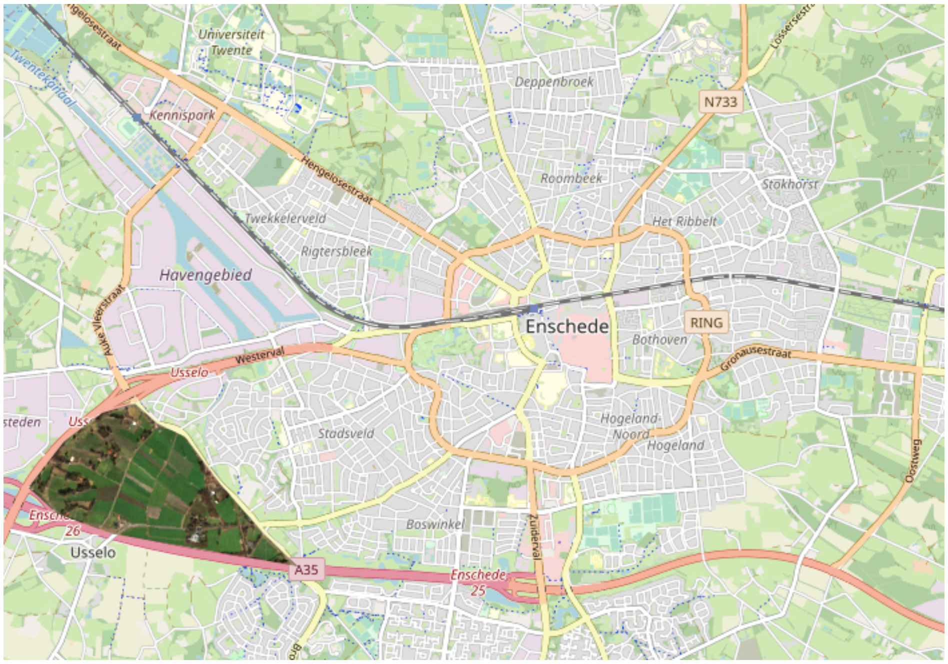

Figure 5. Location of Usseler Es study sites, with respect to Enschede.

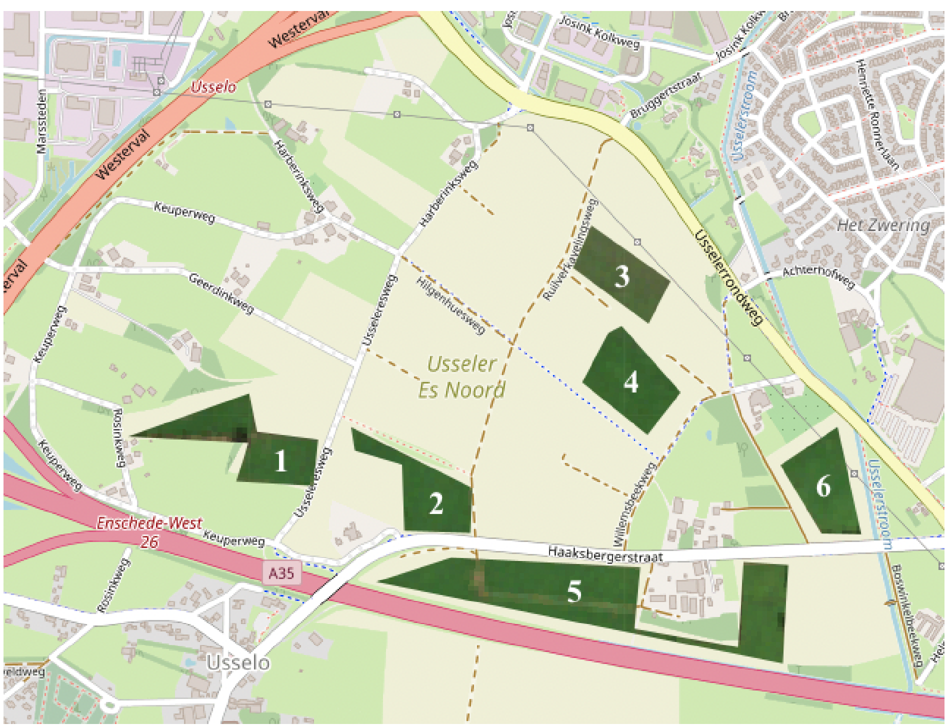

Figure 6. Location of different study areas within Usseler Es: (1) Usseleresweg, (2) Ruilverkavelingsweg 1, (3) Ruilverkavelingsweg 2, (4) Hilgenhuesweg, (5) Haaksbergerstraat, and (6) Usselerscholweg.

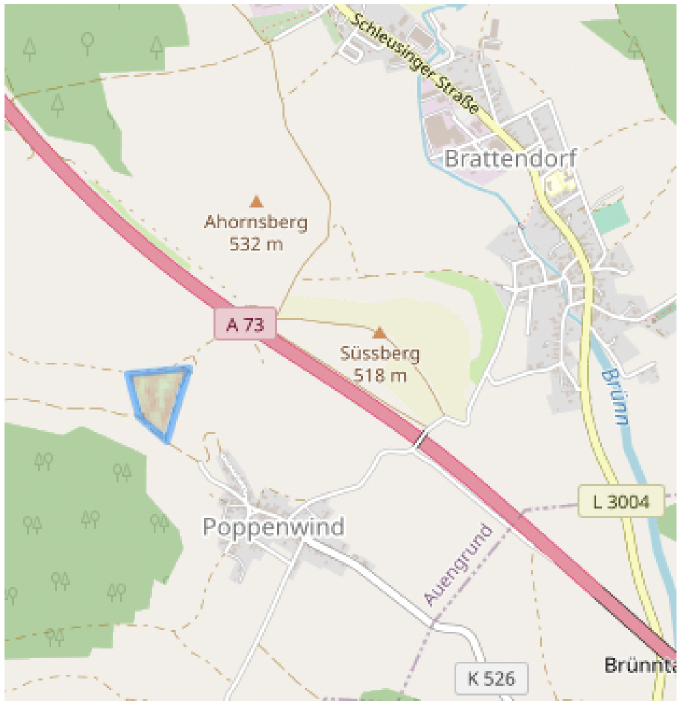

Figure 7. Location of the Kitze study site, with respect to Poppenwind and A73 motorway in Germany (blue boundary).

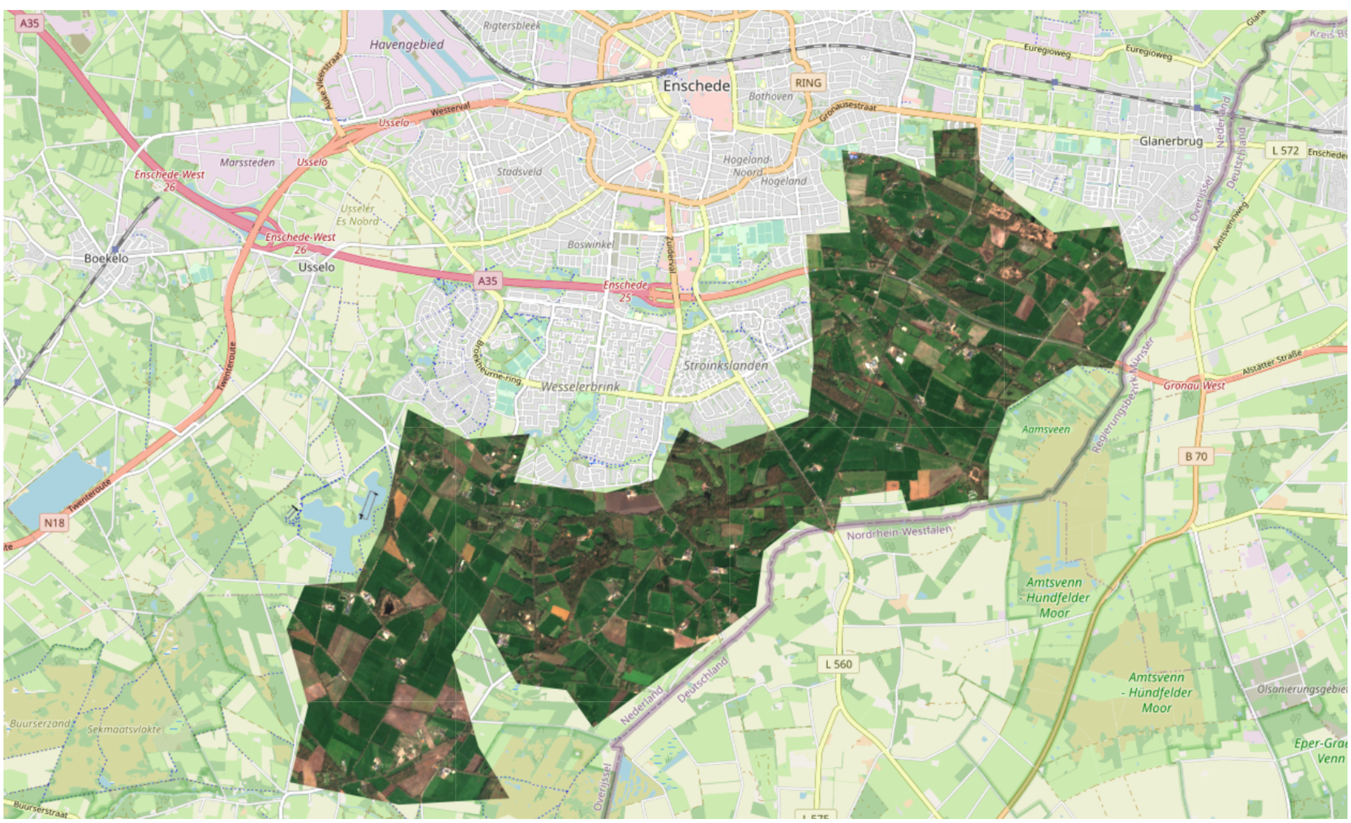

Figure 8. Location of the southeast Enschede study site.

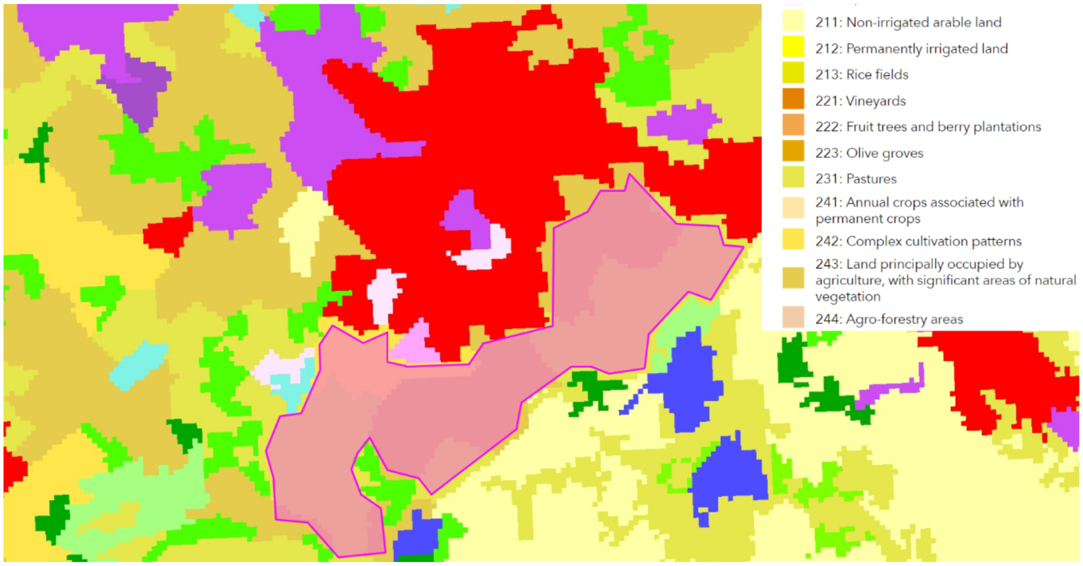

Figure 9. Land cover data of the south Enschede study site.

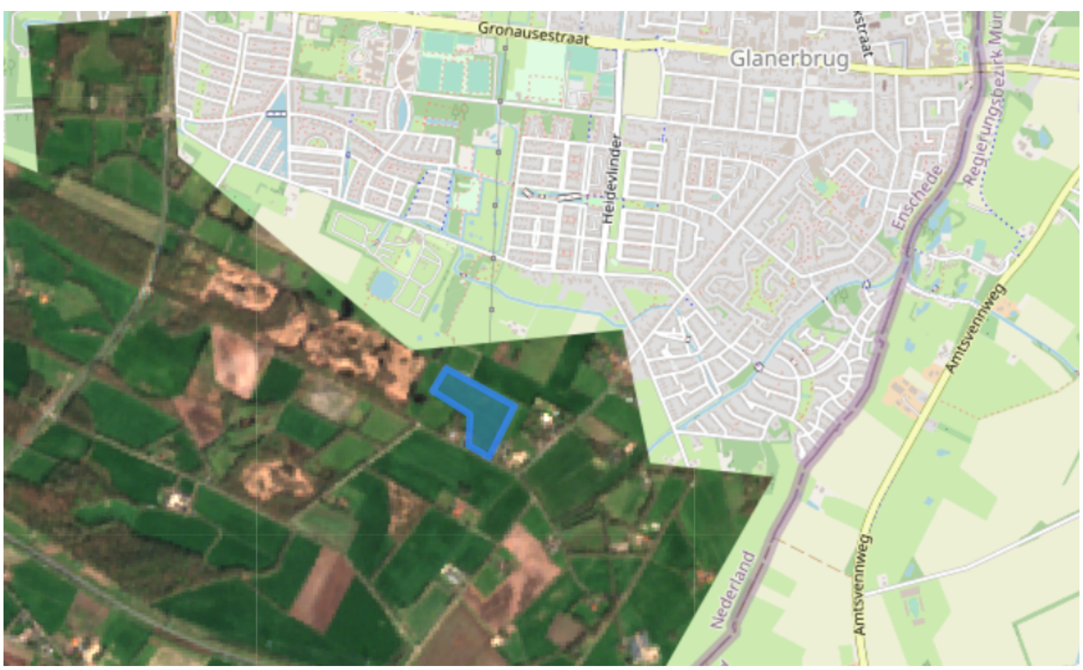

Figure 10. Location of the Kersdijk study site, with respect to Glanerbrug (blue region).

Figure 11. Location of the Berktepaalweg study site, with respect to Buurse (blue boundary).