MASTER

Detecting criminal activity in rural areas
A study into the application of satellite imagery in drugs detection

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Detecting criminal activity in rural areas:

A study into the application of satellite imagery in drugs detection

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Abstract

Because of its detrimental effect on society, drugs criminality is an increasing problem in the Netherlands. The Regionale Informatie en Expertise Centrum Midden-Nederland (RIEC-MN) assists the police in counteracting these subversive activities. An idea under investigation by the RIEC-MN is using satellite imagery to search for drugs criminality in rural areas, where drugs criminality is hard to discover. In a pre-study, interviews were conducted with RIEC-MN employees and other experts to determine which application of satellite imagery was both interesting for the RIEC-MN and technologically feasible. Based on the results of the pre-study, this study focused on detecting cannabis nurseries using infrared satellite imagery and introducing such a technology by the RIEC-MN and the police. Assumed was that cannabis nurseries have a higher temperature than other buildings. To this end an application was developed that combined Landsat 8 infrared satellite imagery and BAG WFS building data to measure the temperature of large amounts of buildings in rural areas. To test the application the temperature of drugs labs found by the police in the past, was compared to the temperature of buildings in their surroundings. However, no significant difference in mean temperature between cannabis nurseries and other buildings was found, meaning that detecting drugs labs through infrared satellite imagery is not possible with the current available free infrared satellite data. The RIEC-MN is recommended to pursue other applications of satellite imagery to investigate drug criminality, such as detecting outdoor cannabis cultivation using satellite data that can distinguish between different types of plants.

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Introduction

In the last decennia technological developments have significantly increased, among others by the combination of different scientific disciplines. One of these fields is geographic data analysis, which has grown remarkedly through the large amount of satellite imagery that has become available. Since the 1960's when the first images of earth from space were taken, the earth is currently monitored by 906 satellites (Mohanta, 2021, 7 juni). The first satellite images were mostly used for intelligence and warfare purposes, currently the increased quality and analysis technology has opened new opportunities to contribute to several other fields. Nowadays these satellites are used for a variety of purposes, such as weather forecasting, crop monitoring, urban planning and environmental sciences. Satellite images have led to improved quality and new opportunities in these fields. The possibilities for applications using satellite imagery are not exhausted. One such relatively new scope is the use of satellites images to detect criminality.

The police is continuously searching for new ways to counteract criminality. A special focus lies on opposing subversive activity, such as drug criminality, which has a negative impact on the integrity of the Dutch society (Tops & Van der Torre, 2014). Special organizations, the RIEC's (Regionaal Informatie en Expertise Centrum: Regional Center for Knowledge and Expertise) have been created to support the police, municipalities and local partners with information and research in the fight against subversive activities. The RIEC-MN, which covers the province Utrecht, the province Flevoland and the Gooi & Vechtstreek in Noord Holland, has identified subversive activities in rural areas as especially troubling. The low population density in rural areas with corresponding lower police activity makes it easier for criminals to go undetected. This makes it an attractive location for synthetic drugs labs and cannabis nurseries. To counteract the challenges of criminality in rural areas, various solutions have been suggested and tried, such as drones to monitor large areas of land and awareness campaigns for farmers (Engberts & Gillissen, 2016). One solution that has been proposed but has not been tried yet is the use of satellite imagery.

Satellite images could be useful because they can be used to easily investigate large areas of land, make it a good tool to monitor rural areas. However, satellite images are difficult to interpret and the processing requires a large amount of technical knowledge before satellite images can be used for criminality detection.

At the same time, if satellite imagery proves to be a useful tool in counteracting subversive drug criminality, it does not mean that the RIEC-MN can and will adopt satellite imagery without issue. Introducing a new technology into a company or organization often comes with its own difficulties. Almost every field struggles with the adoption of new technologies, for example education (O'Rourke & Harrison, 2004), healthcare (De Veer, Fleuren, Bekkema & Francke, 2011), agriculture (Schmitz & Moss, 2015) and even music (Pinch & Bijsterveld, 2004). Governmental organizations are no exception and the (Dutch) police also faces challenges of, for example, how to use a new technology, when and when not to use a new technology and how to combine a new technology with existing technology (De Pauw, 2019). Also, more than most other fields the police faces legal challenges when trying to adopt new technology (Devroe, Matthys, Lodewijk & Moor, 2020). To ensure that the RIEC-MN can use satellite imagery to counteract subversive activity the aforementioned issues need to be investigated and addressed.

The goal of this thesis is to study how satellite images can be used by the RIEC-MN to detect drug criminality. To achieve this goal, the following main research question will be answered:

Can satellite imagery be used to detect criminal behavior, in particular the existence of drug labs, and if so, how can it best be introduced by the RIEC-MN?

This thesis consists of two parts, firstly a pre-study was conducted to investigate the needs of the RIEC-MN concerning the application for drugs detection through satellite images. Also experts were consulted about the technological feasibility of various implementations. Secondly, the main study focused on the construction of an application based on the pre-study and theory regarding satellite technology. It is divided in a method section that focuses on the application, a results section and this thesis ends with a discussion of the results and suggestions for future research.

Pre-study

Design

The purpose of the pre-study is to gain insight into the possibilities and limitations of satellite images as well as the needs of the RIEC-MN. In other words, at the end of the pre-study the main study should have a clear goal based on the results of the pre-study. This goal is conceptualized in the following research questions:

1) What are the concerns and wishes of the RIEC-MN employees concerning an application for drug lab detection?

2) What are the expert opinions about the feasibility of different options for applications for drug lab detection?

To answer these questions consultations with RIEC-MN employees and experts on both satellite images and drug criminality have been conducted. The interviewees and their expertises and affiliations are described in more detail in the participants section. The instruments and procedure sections will describe the set-up and procedure of the interviews. The analysis is discussed in the analysis section and the results of the interviews are given in the results. Finally, based on the results a conclusion is drawn and a direction for this thesis is decided based on this pre-study.

Participants

Experts on both subversive activity and satellite imagery were interviewed. These experts were chosen for the interviews to get a better understanding of criminal behavior that could be detected and what was technically possible with satellite data. An overview of these experts: my supervisors, a data analysist and a geo-specialist from the RIEC-MN. Further interviewees with the RIEC-MN included an advisor for the group Smart Cell Find the

Money and the entire group Buitengebied (Rural areas). Two experts from the Belastingdienst (tax authorities) were interviewed, a data scientist and a GIS-management and a geo analysist. From the Municipality Utrecht a data analysist and a police officer were interviewed. One employee from the Netherlands Space Office was interviewed. Furthermore, a professor of Cognitive Science & AI at Tilburg university was interviewed. Finally, an employee of IMAGEM, a company that specializes in remote sensing and the processing of satellite images, was interviewed.

Instruments

The topics of the interviews were dependent on the expertise of the interviewee and the current questions at hand. Often those questions were based on the literature, e.g. to clarify things that were not clear or to investigate options that come forth from the literature. For example, at one point the option of detecting chemicals from a drugs lab through their effect on vegetation was considered. An expert was interviewed who had worked on a similar task in the past. A question that was asked was: "What changes in vegetation did you detect and what were the issues you faced?".

Procedure

Because of the corona pandemic, the interviews were conducted online through Microsoft Teams. Meetings with supervisors, from the RIEC-MN and the TU/e were usually conducted weekly. A presentation about satellite imagery was given to the group Buitengebied to provide a basic understanding of satellite imagery and to facilitate the brainstorm session afterwards.

It should also be mentioned that a meeting was conducted with an employee of IMAGEM a company that specializes in satellite imagery. IMAGEM is currently in discussion with the police about the possibility of doing a similar project. Some form of cooperation with IMAGEM was proposed, but was ultimately not viable. IMAGEM remains a commercial company which makes sharing of data difficult and it was unclear how long it would take before IMAGEM would get the required permissions from the police to start their project.

Results

Of every meeting, notes were taken that were later summarized into tables. The results of all meetings were discussed with the supervisors. Later these results were summarized in table 1 and 2. Table 1 consist of a list of possible satellite applications that were considered. Included in table 1 are the advantages and disadvantages of each application. These (dis)advantages are based on the meetings with experts on satellite imagery. Table 2 is a list of possible indicators of a location being a drugs lab or cannabis nursery created by group Buitengebied, which are relevant for one of the proposed solutions in table 1. A conclusion was drawn on each application based on its pros and cons in consultation with the supervisors. Of those ideas two seemed doable within the scope of the project: the detection of outdoor cannabis cultivation through satellite imagery and the detection of suspicious buildings through satellite infrared. These are discussed in more detail in the conclusion and in the Background and previous research section.

APPLICATION	ADVANTAGES	DISADVANTAGES	CONCLUSION
Detection of outdoor cannabis cultivation	Doable option, given that it has already been done in some form Can make use of sentinel 2 data with low revisit time (3-5 days)	Outdoor cannabis might be one of the less interesting finds Little is known about the feasibility of	A viable option, discussed in more detail in the conclusion

		cannabis detection in nature reserves Imagem has plans to try this in the future	
Detection of suspicious buildings through infrared imagery	Is useful for both indoor cannabis and synthetic drugs labs, since both emit heat as part of the production process Makes use of landsat 8 data with medium revisit time (2 weeks) Can be easily supplemented with other data	It is questionable if the 100m resampled to 30m resolution is good enough for accurate temperature measurements of buildings This application requires somewhat detailed data about (empty) buildings	A viable option, discussed in more detail in the conclusion
Detection of suspicious chemicals through SWIR bands	Detecting the right chemical provides very strong evidence that a drugs lab exist at that location Provides insights that are hard to require otherwise	It is unknown which satellites have the correct SWIR bands for drug related chemicals, if any Chemical concentration are possibly too small to be detected by satellite	Although it is certainly interesting to find drugs labs through the chemicals they use, doing this with open access satellites will be very difficult.
Detection of chemical (dumps) through their effect on the environment	Can provide indirect information about chemicals Even if not drug related, there are no legitimate reasons to dump chemicals in the environment Chemicals have the biggest impact on plants, so can make use of sentinel 2 data with high revisit time (3-5 days)	Effect of chemicals on the environment are very hard to distinguish from natural effects such as drought or animals Various plants will look different to the satellite and react different to chemicals	Although this option can be tried, it is unlikely that the disadvantages can be overcome, meaning that the application would not be to find chemicals among the natural variation of vegetation
Detection of drug labs through various indicators, such as shown in table 2	Can provide strong evidence of a drugs lab, based on the number of indicators	At the resolution of available satellites (0.5m by 0.5m) many indicators (waste containers, water pump, security measures) are	Given how much detail most of the indicators require, it is unlikely that the limitation of resolution can be overcome. Even taken

	Large number of indicators, so likely at least some are useful Can be easily supplemented by or used to supplement other data	one pixel or less, making it difficult to distinguish them Revisit time of the satellietdataportaal is high (1 month or more) Indicators are mainly untested and hard to test during the project	together, the indicators that do not require a high resolution will provide not enough evidence to really define a building as suspicious. Parts of this applications can be used in other applications
Detection of drug waste dumps	Provides more insights into drug criminal behavior	Provides less information about criminal behavior than other applications Are usually quickly detected by other sources, whereas detection likely requires data from satellietdataportaal with a high revisit time	This application requires too detailed information that can only be gotten with a very high revisit time. It would provide too little advantage over detection by other sources
Applying neural nets to automatically detect drugs labs or cannabis cultivation	Could provide detection without the need to find and verify indicators or strategies beforehand Found indicators could be used outside of the project as well	The task is very complex, making it hard to learn for a neural net There is likely not enough training data The training data (and test data) is likely inconsistent due to atmospheric differences	Neural nets without any prefiltering or focus will be unlikely to work given the absence of sufficient high quality training data. They can however be used in other applications on more specific tasks, although the same limitations apply there.

Table 1: An overview of the possible applications for satellite imagery and their advantages and disadvantages.

INDICATOR	EXPLANATION
People sleeping on location	People sometimes sleep on the same location as the drugs lab to prevent the appearance of a lot of people coming and going
Remote location	To prevent detection, drugs labs are usually located on remote locations

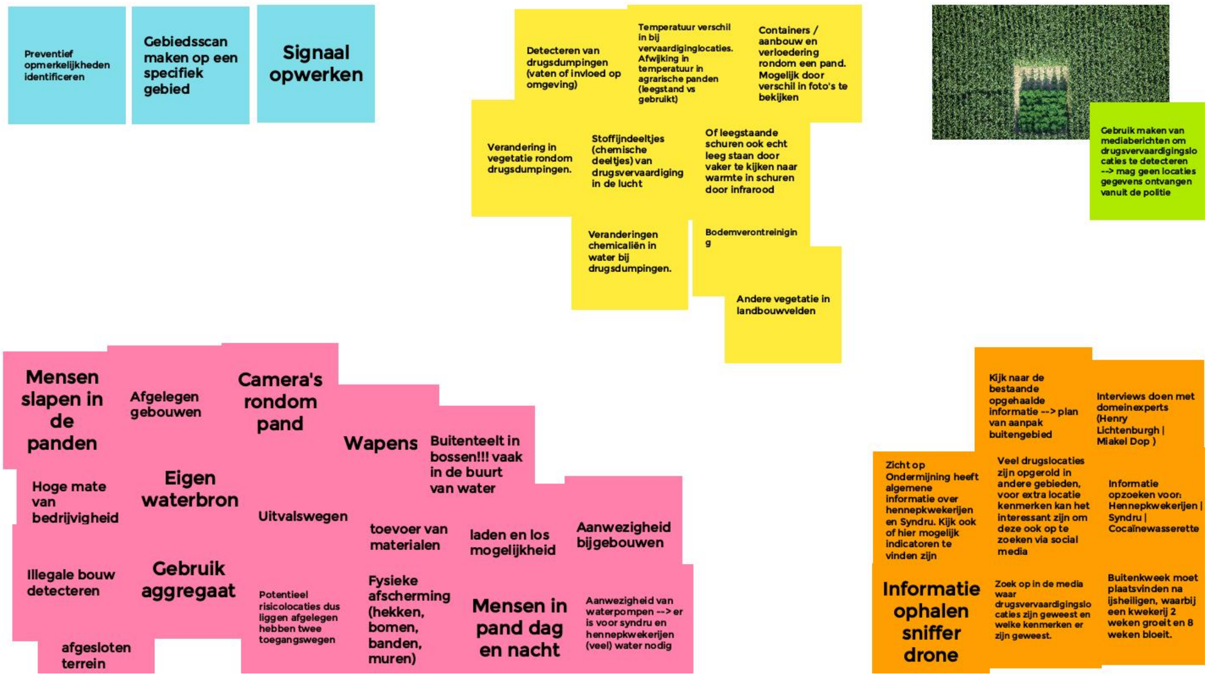
Cameras on buildings	Cameras are used as security measure to keep out unwanted people
Weapons	Drugs criminals are often violent or want to defend themselves against violence
Loading and unloading possible	To set up a drugs lab, it should be possible to load and unload equipment onto the site, preferably unseen
Existence outbuildings	Drugs are sometimes created or cultivated in separate buildings, when the main building is not suitable for some reason
Physical shielding	Physical shielding such as fences or bushes makes it harder to detect what is going on within a location
Own source of water	Both the cultivation of cannabis and the creation of synthetic drugs require a large amount of water and drawing that from the municipal water supply could draw suspicion
Existence water pumps	The same reason as above, a lot of water is needed and it might need to be pumped from somewhere
Illegal building activities and materials	Setting up a drugs lab requires materials and building activity that, for obvious reasons, cannot be done legally
High amount of activity	Running a drugs lab often requires more activity than is normal for the location or the time of the day
Existence of containers	Sometimes containers are used to make or cultivate drugs in as well as to store water and drug waste.
Deterioration	Often drugs criminals do not care much about the upkeep of the property around the drugs lab
Arterial roads	Drugs criminals often make use of arterial roads to leave and enter the property undetected

Table 2. An overview of the indicators for drugs labs gained from the brainstorm session with team Buitengebied (team rural areas), with explanations

Some more detail on the applications that were rejected will be given below. The detection of chemicals released in drug production either directly or through their effect on the environment was rejected purely based on its difficulty. IMAGEM believed this could be done and included an example in the presentation they gave the police. However, that example was based on an existing drugs lab instead of trying to find new suspicious buildings. And IMAGEM does have access to satellites with higher quality than open source satellites, which might explain the differences. Another expert indicated that in a previous project that tried to find pollution with heavy metals through their effect on the environment, they could not differentiate between the effects of the pollution and the natural variation in vegetation.

The brainstorm session, although interesting, did not provide many insights that could be used for the detection with satellites. The experts in the brainstorm session were probably not accustomed to detecting drugs labs from above. As such, most indicators are, as indicated in in the disadvantages, too small to detect. It might be possible to use some indicators in other solutions, for example indicators such as arterial roads and remote location can be easily implemented based on geographical data. The jamboard used in the brainstorm session is displayed in Figure 1.

Figure 1. The Jamboard



The jamboard used for the brainstorm session with team rural areas

As final option training a neural net to detect possible drugs labs was considered. There are several ways to do this. For example, you can train a neural net just on satellite images of buildings, only tell it whether it is a drugs lab or not and let the training figure out how to detect differences. You can supply the neural net with a set of information, which for example could include electricity and water usage, location and building history and let it train what is important and what indicates a drug lab. Or you could train a net or several nets on recognizing specific things or characteristics, for example the indicators in table 2, and mark a building as suspicious when a certain number of suspicious characteristics are found. However, all of these approaches share the same issues. The problem is quite complex, there are huge differences between drugs labs and even humans cannot easily recognize them even with auxiliary information. At the same time the amount of trainings data is small, there are not that many drugs labs and access to data about them can be juridically difficult. All in all this meant that neural networks were not viable as a detection method, although other machine learning techniques might still be used in the application.

Conclusion

Based on the discussion with RIEC-MN employees, an application could assist the RIEC-MN and the police with the detection of possible drugs labs. It should be able to scan larger parts of rural areas and indicate which buildings are suspicious. Those buildings can then be monitored more closely, or the information, together with other sources could be used as a basis for further investigation. The application should preferably run automatically without the need for much human maintenance or interpretation. For example, its output could be a map with suspicious areas that can be easily supplied to the police and the application can be run once a week to check if something new pops up. It should also be possible that the output of the application is used in another application, e.g. as input in a machine learning model. Finally, the application, to comply with privacy laws, should also not provide information about buildings immediately, instead only indicating that a suspicious building is found within a certain area. Then if the RIEC-MN has additional information to go on, they can manually decide to read out the exact location of the building.

Based on the discussion with experts, two options were selected that seemed viable, the detection of outdoor cannabis cultivation and the detection of suspicious buildings through infrared imagery. These options were investigated further. An exact overview of what these options entail and the challenges that come with them can be found at the end of the section Background and previous research. Both options were considered equally promising.

After some consideration, it was decided to go with the detection of suspicious buildings in rural areas through infrared satellite imagery as the goal for this project. This topic was chosen because indoor cannabis cultivation is a larger problem than outdoor cannabis cultivation and the infrared images could also be used to detect synthetic drugs labs. In other words, the findings of an application based on infrared satellite images are more interesting to the RIEC-MN than an application used for the detection of outdoor cannabis.

Main study

Research questions

The goal of the main study is to construct an application that could be helpful for RIEC-MN employees in their fight against drugs criminality. Based on the pre-study, the focus of the application is determined to lie on the detection of suspicious buildings through infrared satellite imagery. Based on this the main research question of this thesis is specified as follows into two sub-questions:

1. *Can infrared satellite images, from Landsat 8, be used for the detection of suspicious buildings in rural areas?*

Next to the technical aspects of the research question, it is clear from the pre-study that for an application based of this research question to be useful for the RIEC-MN, its design with respect to the information needs and wishes of RIEC-MN employees should also be considered. To address this need the following research question will be answered:

2. *Given a successful answer to 1., how can an application based on this thesis be designed so that it optimally addresses the needs and information requirements of the RIEC-MN?*

Background and previous research

This section gives more information and previous research on drug criminality in rural areas, on indoor drug creation and on satellite imagery. At the end, it provides more detail about the two options specified by the pre-study, the detection of suspicious buildings through infrared imagery and he detection of outdoor cannabis cultivation.

Fighting subversive crime in rural areas

Subversive activities are a growing problem in the Netherlands. This has several consequences for citizens, the government and even the environment. Citizens are increasingly troubled by the activities of (drug) criminals and the border between the over- and underworld fades. (Kolthoff & Khonraad, 2016). Examples of this problem include being affected by the violence of drugs criminals or more general feelings of unsafety. Municipalities, especially in Noord-Brabant, report that organized crime influences their elections and policy making (Fijnaut, Bovenkerk, Bruinsma & Van de Bunt, 1996). Finally organized drug crime also has a negative impact on the environment. The drug manufacturing process leaves many waste products which for obvious reasons cannot be processed officially and safely. Instead these waste products are often dumped directly in the surrounding environment or put into barrels and left in remote locations.

To get an overview of the scope of the problem, in 2019 366 synthetic drugs locations were discovered, from which 90 were used for production, the other locations for storage and dumping. Examples of synthetic drugs are extasy, amphetamine (speed) and crystal meth. In the same year 3285 indoor cannabis nurseries were found (Kruize, Gruter & Suchtelen, 2020). It should be noted that a lot of cannabis nurseries are relatively small, 82% were found inside houses, while synthetic drugs labs are set up larger and more professionally. While home-cultivated cannabis usually does not have the subversive effect that other forms of drug cultivation have, it does carry its own consequences such as an increased fire risk because of the wiring required, an increased risk of other crimes and nuisance for neighbors (Berger, De Berk, Beijers, & Blokland, 2019). Cocaine and heroin are, as far is known, not produced in the Netherlands and only imported (Kruize, Gruter & Suchtelen, 2020).

One of the main focuses of the RIEC Midden-Nederland is criminal activity in rural areas. Rural areas often have a lower population density and police activity, making it easier for criminals to work undetected. This makes it an attractive location for drugs labs and cannabis nurseries. A lot of farmers report that they have been contacted by drug criminals who want to use their barn or land for drug manufacturing. It can be difficult for farmers to refuse these requests, either because they have monetary troubles or because they are actively pressured or threatened by the criminals. The size of rural areas makes it difficult to effectively patrol, making it hard to prevent drugs criminality and other subversive activities.

Satellite imagery as a tool for crime detection

Satellite images could offer a solution for detecting drugs criminality. By using open source satellite imagery, it is possible to have software quickly search large quantities of land. Locations that are flagged as suspicious could be checked more efficiently with less manpower. Although it is possible to get similar results with air photos, that often requires a municipality or police force to specifically hire a plane to make those photos which is expensive and cannot be done often. In contrast, an application based on satellite images could use exclusively free, open-source images and could be run almost continuously, Consequently, the goal of this project is to find and implement a good application of satellite imagery for the detection of subversive activity in rural areas.

Satellite imagery is already used in a multitude of ways. In the context of criminality detection through satellite imagery the target is most often environmental crimes (see e.g.

Duan, Cao, Shen, Liu & Xiao, 2019). The companies Satelligence and Reef Support have a somewhat similar goal in mind. Satelligence investigates the supply chain of companies to verify that it is indeed as sustainable as claimed. Satellite images are used for example to detect deforestation. Reef Support uses satellite imagery to monitor coral and to make predictions about the developments of coral reefs.

A disadvantage of satellite images is that the resolution and refresh rate of images is often too low to detect individual crimes. For this reason, applications for satellite imagery for crime detection often focus on more passive detection or analyses methods. An example of this is the article by Najjar, Kaneko and Miyanaga (2018). They combine satellite images with a huge amount of historical crime data to make a prediction model for the criminal activity on a location. The resulting model can predict criminal activity at new locations with reasonable accuracy and could for example be used to indicate dangerous or interesting places in cities without good crime reports. Chen, Weeks and Kaiser (2005) use a similar method with a more statistical approach to find common characteristics between places with a lot of criminal activity.

More relevant for the topic at hand are the applications for satellite imagery in the detection of (outdoor) cannabis nurseries. The article by Lisita, Sano and Durieux (2013) tries to identify areas were cannabis could be cultivated based on satellite images. This is done by looking at characteristics common to outside cannabis nurseries (e.g. remote, plants are a certain type of green, access to water). Although the method and results are certainly interesting it should be noted that this article, like many such articles, focusses on Brazil, so found methods and characteristics cannot be copied one-on-one. Similarly, Houmi, Mohamadi and Balz (2018) managed to differentiate between cannabis and other plants in satellite images. However they also did not test this method on new data, so it is difficult to say how effective this method is in detecting new plantages. Finally cannabis can also be detected using infrared or near infrared (Pereira, Pimentel, Amigo & Honorato, 2020) although to do this the satellite has to be equipped with the right sensors.

No studies have been done that specifically study the detection of drugs lab with infrared satellite imagery but similar studies have been done that study the temperature of buildings. For example, Kaplan, Avdan and Avdan (2018) study the effect of land use on heat islands in cities. If their research could be reproduced on a smaller scale, it could possibly be used to detect drugs labs by detecting their relatively higher temperature.

Quality of satellite images

With respect to the satellites that can be used as a data source, there are several factors of importance. First of all, the resolution, so the quality of the images that determines the smallest details that can be seen, differs between satellites. Secondly, the revisit time, the time the satellites takes to take a new picture of the whole world or the 'refresh time' also differs. Finally, although the satellites considered for this project all take color images, they differ in their capabilities to detect wavelengths in the infrared and short wavelength infrared (SWIR) spectra. Infrared detection allows a satellite to measure temperature, while SWIR is used to accurately measure specific things such as water or plants. For this project specifically it is also relevant that the satellite data is freely accessible instead of commercial.

Indoor cannabis cultivation

It is commonly known that cannabis cultivation is accompanied with a lot of heat. Part of this heat comes from the strong electrical lamps that are used to provide the necessary lighting conditions for the cannabis plants. However, especially in colder weather the cultivation room itself also has to be heated. Cannabis plants can survive temperatures from 15 to 29°C (Vanhove, 2014), but generally grow optimally in temperatures between 20 and 25°C (Jin, Jin & Chen, 2019), with some tropical variants preferring temperatures 25 - 30°C

(Upton, Craker, ElSohly, Romm, Russo, Sexton, et al., 2013). The outside temperature of a cannabis nursery can differ significantly based on the building, its isolation and the current weather. In the literature no absolute outside temperature values of cannabis nurseries could be found. Instead, when the police uses infrared cameras to detect indoor cannabis growth, they usually compare a building to its neighbors or similar buildings, buildings with a significantly different heat pattern then stand out. Indoor cannabis cultivation also requires a significant amount of electricity and water.

Synthetic drug creation

The creation process of synthetic drugs differs significantly per drug and the specific lab involved. A list of factors common to most drugs labs given by experts can be found in table 2 in the pre-study section. An important aspect to consider is the heat produced by a synthetic drugs lab. The experts in the pre-study agreed that synthetic drugs labs produce heat, but there is no literature on how much and the police does not regularly search for synthetic drugs labs with infrared cameras. It should be noted that criminals can also take actions, such as cooling, to reduce the released heat and make detection more difficult.

Detection of cannabis criminality

One possible application of satellite data is the detection of cannabis that is cultivated outdoors. Although the majority of cannabis in the Netherlands is cultivated indoors or in greenhouses, satellite detection of outdoor cannabis would nevertheless be useful for hard to check locations. After all, in rural areas the manpower is often not present to check a location in person, while a satellite can check the whole country in a couple of images. If a high level of accuracy could be reached it would also provide valuable insights into the prevalence of outdoor cannabis cultivation in the Netherlands. Since outdoor cannabis cultivation is likely to happen in agricultural fields or nature reserves, the main challenge is to differentiate between cannabis and other vegetation. The Sentinel 2 satellite will likely be instrumental to this task because of the many SWIR bands dedicated to vegetation it has. This has a disadvantage that detecting cannabis plantations smaller that the sentinel 2 resolution of 10m by 10m will be difficult or near impossible. Alternatively radar satellite data from the NSO could possibly be used for cannabis detection at a 5m by 5m resolution. From all outdoor cultivation, cannabis in agricultural fields will likely be the easiest to detect because it can be more easily compared to surrounding uniform vegetation. In nature reserves the more diverse vegetations might hinder detection and cannabis might be hidden underneath trees. In both cases satellite data should be combined with existing map data to define a search area.

Another application of satellite imagery uses infrared to detect suspicious buildings. Both cannabis nurseries and drug labs produce heat. By using the Landsat 8 satellite to measure the temperature of buildings, it is possible to identify unusual activity in buildings. The satellite data would have to be combined with e.g. cadaster data to note activity in supposed empty buildings. Alternatively, it would be possible to measure higher temperatures than the purpose justifies such as temperatures of above 20 degrees Celsius for a simple storage shed. Accuracy could be improved by more auxiliary information such as the amount of isolation in the building or its recent energy usage. Whether this information can be retrieved and used without violating AVG regulations is unclear. Here too the application is limited by the resolution of the satellite images. Landsat 8 offers infrared images a resolution of 100m by 100m which can be resampled at 30m by 30m. At this resolution most buildings will be a single pixel or less, making it difficult to accurately measure temperature.

Method

During the thesis, an application was made to answer the question: How can infrared satellite images be used for the detection of suspicious buildings in rural areas? This section focusses on this application and the process of its creation. It will provide an overview and justification of the choices made at the start, give an overview of the data used, explain the structure of the code and go briefly over the issues faced during the project. At the end the design of the interview is given.

Set up choices

The data from several satellites was considered for the application. First of all, Landsat 8 a satellite owned by the United States government which data is freely accessible. It can detect visible light and some bands in the SWIR range, but most importantly, it can detect infrared which is uncommon among open source satellites. However, its resolution is quite poor with 30m by 30m and with 16 days its revision time is longer than most. Sentinel 2, launched by the European Space Agency is another open access satellite. It has a slightly better resolution and revisit time of respectively 10m by 10m and two to five days. It also has quite some sensors in the SWIR range mostly to accurately measure plants and water. Worldview 2 has a good resolution of 0.5m by 0.5m and has SWIR bands that can be used to measure the surface through clouds and smoke with reasonable accuracy. However only part of its data is publicly accessible and since that part does not cover the Dutch rural area it is unlikely that this satellite can be used. Finally there is Superview which has a similar resolution of 0.5m and 0.5m and a revisit time of one to four days. Its data is not open access but can be accessed through the website Satellietdataportaal (Link) from the Netherlands Space Office. After some consideration it was decided to use Landsat 8 images for the application. Its infrared bands make it possible to detect criminal activity in buildings in ways that other satellites cannot, while its limitations in resolution and revisit-time can be worked around.

The application is written in the programming language Python, mostly inside of the programming environment Google Colabs. The application uses Google Earth Engine, a geospatial processing service that can be used as a Python library. Google Earth Engine offers a lot of functionality related to the acquisition and processing of satellite imagery. This includes functions specifically for the acquisition of Landsat 8 imagery making it quite suitable for this project. The infrared bands from Landsat 8 measure the ground radiance, however for the purposes of the project the land surface temperature is a better measure.

Data

Detecting suspicious buildings based on their temperature requires not only infrared images, but also information about the buildings themselves. At the most basic level information about the location of the building is required, but preferably information about its surface area, purpose and current state of use is also available. The BAG (Basisregistratie Adressen en Gebouwen: Basic registration addresses and buildings) offers this information publicly and freely. The information from the BAG is retrieved through the BAG API which is explained in more detail below. To distinguish between urban and rural areas the data is supplemented with a governmental dataset on urbanity that is similarly publicly available. Finally since the information from the BAG on the purpose of a building is too broad to be of use, a KvK (Kamer van Koophandel: Chamber of Commerce) dataset which includes to aims of businesses and their addresses is used, which is bought monthly by the RIEC-MN.

Code

The land surface temperature or LST is the temperature as measured by putting your hand to the ground, or this case, the roof. It is calculated from the Landsat 8 infrared bands and auxiliary data using the algorithm and adapted code from the paper by Ermida, Soares, Mantas, Göttsche and Trigo (2020). The algorithm provides the LST for an area chosen, usually the entire Netherlands, for every date that Landsat 8 collected data. This results in a series of 'maps' of LST data for every date of data collection. The temperature data from Landsat 8 includes so called quality assurance bits which provide per pixel information about the quality of the temperature data. Pixels for which the quality assurance bits indicated that there is no information, for example because of clouds or errors, are denoted as missing.

BAG data can be acquired through several ways, for this project the BAG WFS (Web feature service) is used. Through the API the data for a lot of buildings can be requested at the same time, while allowing for some basic filtering on location. Using the WFS all buildings in central Netherlands can be downloaded in batches of a thousand buildings at a time. Since the WFS only gives the coordinates of a building, a geolocator API is used to get the address and postcode. Next to the location of a building, other data is also collected, an overview of which can be seen in table 3 with the BAG WFS source. The data from all buildings is then stored internally to be combined with the satellite temperature data.

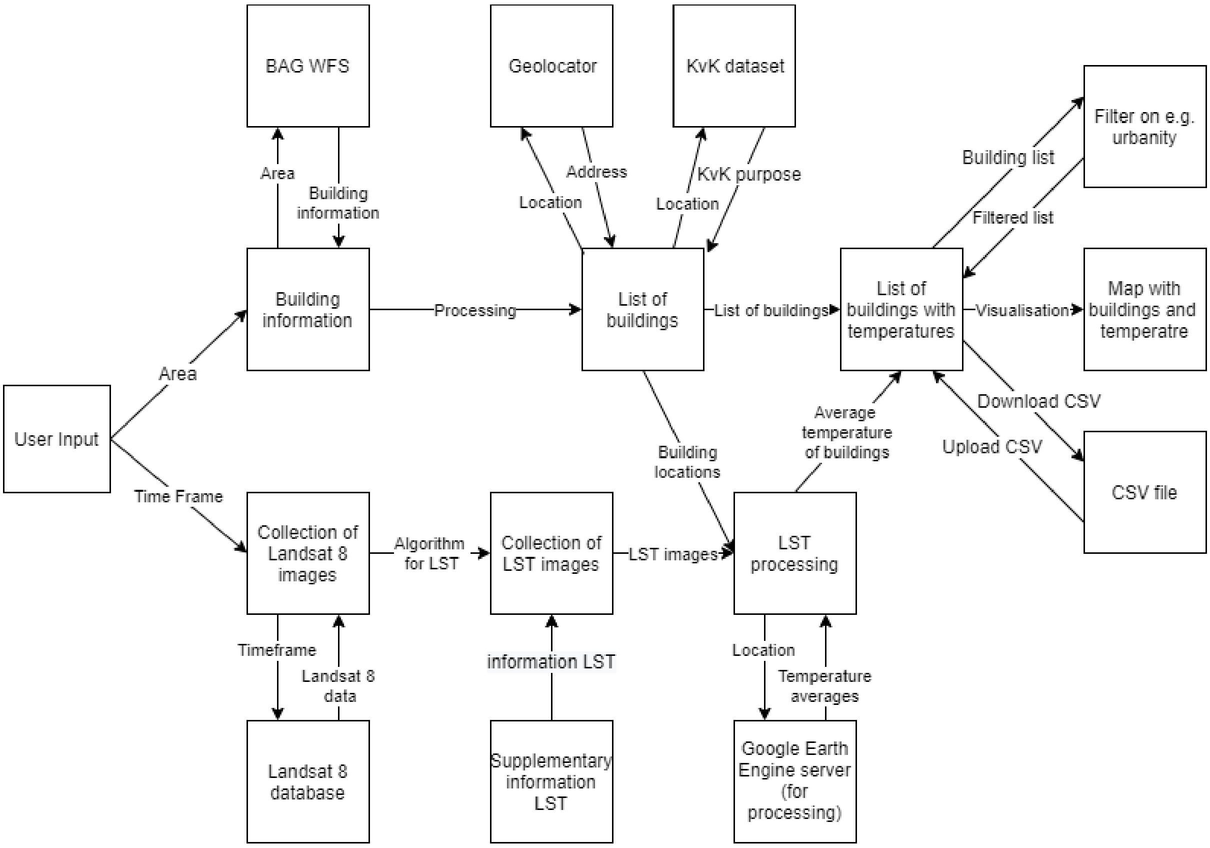
DATA	SOURCE	EXPLANATION
BAG ID	BAG WFS	The BAG ID that is given to every building
Coordinates	BAG WFS	The coordinates of the building in Rijksdriehoekscoordinaten
Building status	BAG WFS	The current status of the building, e.g. "In use", "empty", "demolition planned".
Building goal	BAG WFS	The broad, planned function of the building, e.g. "Living", "industry", "sport or recreation"
Construction year	BAG WFS	The construction year of the building
Address	Geolocator	The address of the building based on its coordinates
Municipality	Geolocator	The municipality where the building is located
Urbanity	CBS Urbanity dataset	The urbanity of the municipality where the building is located, on a scale from 1: very urban, to 5: countryside

KvK building goal	KvK Dataset	The goal of the company in the building according to the KvK, missing, if no company is established at that building
Average temperature	Processed Landsat 8 data	The average temperature at the location of the building
Start date, end date	Processed Landsat 8 data	The start and end date on which the average temperature is based
Number of datapoints	Processed Landsat 8 data	The number of not missing datapoints the average temperature is based on

Table 3, an overview of the data stored about a building with its source and explanation.

After the data from the buildings is received through the BAG WFS, the land surface temperature will be measured as described above. The average temperatures for all buildings that have similar characteristics, such as purpose and ground area, will be calculated. The difference with the average temperature for every building is calculated and stored. To prevent errors the average temperature is only compared to buildings with the same amount of datapoints. Figure 2 shows a flowchart of the steps the data goes through in the application.

Figure 2. Flowchart of the code



A flowchart of the data flow in the application after the user submitted a request for data given a certain area and timeframe.

Usability

The way the application is usually used is by specifying a location or area and date or set of dates that need to be investigated. The application will return a building or list of buildings with the associated temperature and other data. If a specific building is investigated its temperature can be compared to that of surrounding buildings. If an area is specified the buildings are compared to each other. A list can be filtered on temperature and urbanity. The building(s) can be downloaded as a csv file or displayed on an interactive map. Other functionality exists to re-upload csv files for further analysis and to analyze locations of existing drug labs purely for evaluation of the application.

Interviews

Finally, to ensure the application is usable by the RIEC-MN group interview(s) will be conducted with employees from the RIEC-MN. The interviewees will be asked about their thoughts on the design of the application, their information requirements and their needs and that of their colleagues. The interview(s) will be conducted in person if possible (depending on the then applicable corona measures) or in Microsoft Teams otherwise. The interview will be recorded, coded and thematically analyzed.

Issues

During the project various issues came up that needed to be addressed. Here follows an overview of these issues and their solutions.

At the start of the project the first issue was choosing the correct programming environments. Several options such as Geopandas and GIS were considered, but after some research Google Earth Engine was chosen, as mentioned, because of its ease of use regarding Landsat 8 images.

Getting the LST from the Landsat 8 thermal images also required some work. As mentioned the application uses the algorithm from the paper by Ermida, Soares, Mantas, Göttsche and Trigo (2020). However, this algorithm was written in the JavaScript version of Google Earth Engine so converting it to Python took some time.

After getting the LST, the average LST for a specific building over a time period had to be calculated. Downloading data from the Google Earth Engine server to the client takes a significant amount of time and should be minimized to speed up the application. The current application makes all necessary calculations server side and downloads only once, the average, to client side. It was surprisingly difficult to make Google Earth Engine consider only non-missing values for the average. Quite some time was spend in the Google Earth Engine documentation and the solution was found by trial and error.

Comparing the averages of buildings can run into difficulties when not all buildings have the same amount of datapoints. Since the outside temperature and thus the LST differs significantly from day to day, a missing or additional datapoint can have a huge influence on the average LST of a building. To reliably compare averages, the application has an option to only compare buildings with equal amounts of datapoints. Getting the amount of datapoints for a building came (again) with some client/server-side issues, but was easier to solve than getting the average for a building. This approach does have the disadvantages that buildings are now compared with a smaller, unequal and unpredictable number of other buildings. Especially if other filtering is applied it can lead to unreliable comparisons.

The implementation of the BAG WFS came with its own issues. First of all, how to implement a WFS into Python. The Python library OWSLib was used which, although easy to implement, did not support 2.0.0 WFS versions. The BAG WFS can be used with older versions, as the change to 2.0.0 is quite recent, but this meant some features, most noticeable the possibility to filter on buildings characteristics, could not be used.

The coordinates used for buildings in the BAG are in Rijksdriehoekscoordinaten, a coordinate system specifically for the Netherlands. This raises some issues with Landsat 8 data which is in the widely use WGS84 coordinate system. The algorithm from https://thomasv.nl/2014/03/rd-naar-wgs/ (website is no longer online) was used to convert to WGS84 and later on, for other purposes, from WGS84 to Rijksdriehoekscoordinaten.

The BAG WFS does not provide an address, only coordinates. To get an address for a building, the Python library GeoPy is used, which provides functionality to go from coordinates to an address and vice versa. For an unknown reason it does not always provide the municipality with the address. As a workaround, if the municipality is not provided by GeoPy it is found using the postcode and street name in a RIEC-MN dataset which has all three.

Since the focus of this thesis lies on rural areas, the application needs to be able to differentiate between buildings in urban and in rural areas. Making this selection based on comparing the location of a building with a map of all rural areas was considered, but such a map was not readily available and such a comparison would be computationally slow. Currently the selection is made based on the municipality where the building is located, with a CBS dataset providing the urbanity or 'ruralness' of each municipality. This means the selection is somewhat imprecise and can only be done after the relatively time consuming coordinate-to-address conversion, but it was the best solution found.

The BAG WFS does not directly provide address information so when a building needs to be found by its address, the address is first converted to a coordinate, the buildings nearest to that coordinate are found and the correct one is selected by comparing the addresses. When searching for a building based on a set of coordinates, the procedure is the same only the first step with address-to-coordinate conversion is not needed. To ensure a building is found even with small errors in the coordinates, the lower-left and upper-right coordinates of the BAG are used for checking a building. This seemingly roundabout procedure is needed because the BAG WFS does not offer a way to directly search for a building based on its coordinates.

Since Google Colab runs in the cloud, files cannot easily be loaded or saved locally. To prevent having to manually load each file each time the application was restarted, Google Drive was linked to Colab and the files were stored there.

Investigating a lot of buildings can take hours or even days. It often happened during testing that an error not directly related to the program, e.g. a connection error with one of the web services or Google Colab timing out would crash the application. Since these kinds or errors are almost unpreventable the option was created to investigate an area or number of buildings iteratively, where every thousand buildings are saved to a file in the cloud. In the case of a crash the user can restart the application where it left off and later combine the two files.

Analysis

It is useful to first get impression of the data before starting an analysis on actual cannabis nurseries. To this end two heatmaps of two areas in central Netherlands are displayed in figure 3. It is clear that the environment has an influence on the land surface temperature, in the top image the river, highway and building can be regonised and in the bottom image the barn has a higher temperature than its surroundings. However, the maximum temperature difference is small, 7°C in the top image and 3.5°C in the bottom image. It also shows that there are no straight borders in the temperature data even where you would expect them, as if an more accurate heatmap has been taken and slightly blurred. This is possibly caused by the resampling of 100m by 100m infrared pixels to 30m by 30m infrared pixels (Acharya & Yang, 2015).

Figure 3. Example heatmaps

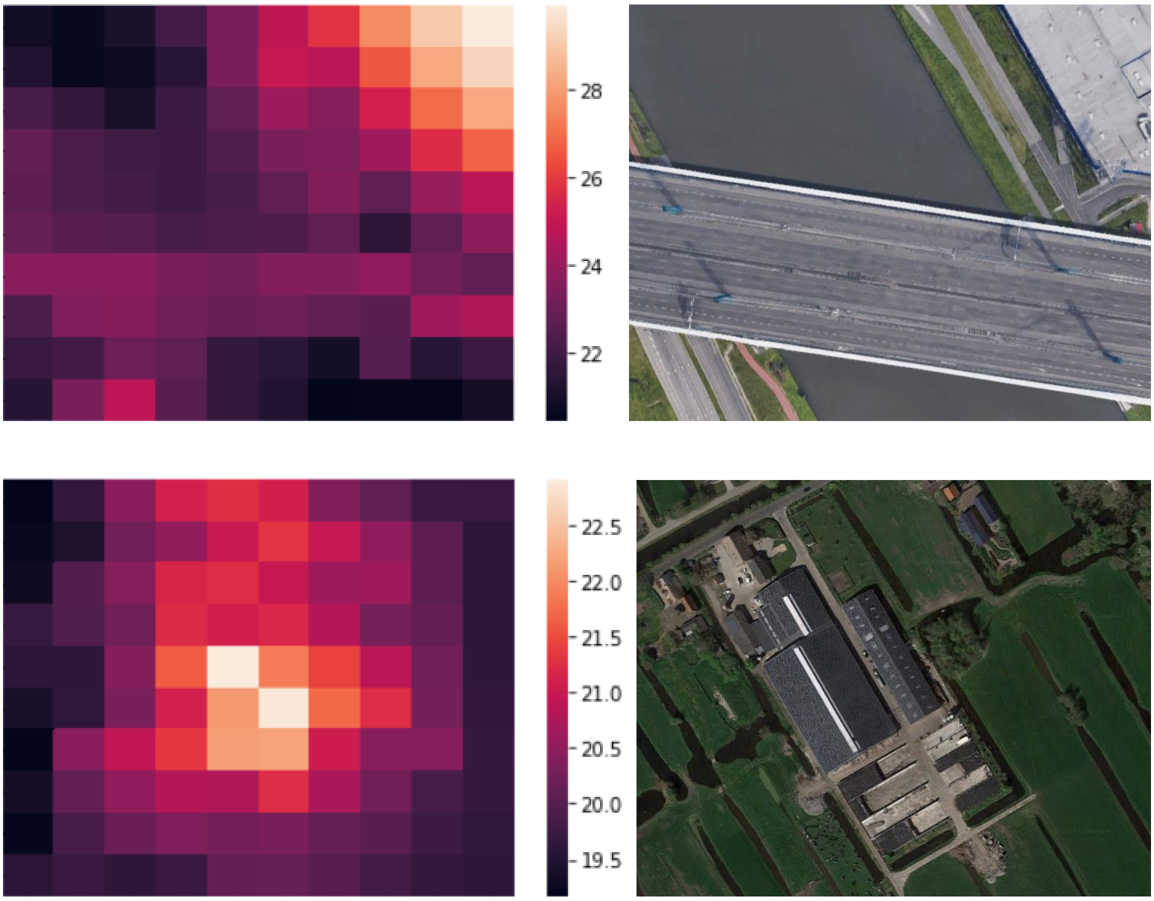


Figure 3, examples of Landsat 8 data displayed as heatmap with the corresponding color image for reference. Top images are centered around 52.061015, 5.097435 and temperature data was collected from 01-04-2021 till 01-10-2021. Bottom images are centered around 51.985173, 4.879331 and temperature data was collected from 01-01-2019 till 01-01-2021. Color images taken from Google maps.

Before a classification of buildings into suspicious or not suspicious can be made, the temperature difference between normal buildings and cannabis nurseries should be known. Since data on the mean outside temperatures of cannabis nurseries could not be found in the literature, it was attempted to determine this empirically based on a number of cannabis nurseries found by the police in the past. A dataset was provided by the RIEC-MN on cannabis nurseries found in Central-Netherlands. The dataset included 1093 entries in total, from the year 2017 till the start of 2021. Because the focus of this study lies on drugs locations in rural areas, only buildings in municipalities with low or very low urbanity were used. This was based on the CBS urbanity dataset mentioned in the method. The urbanity is measured in environmental address density (omgevingsadressendichtheid), which stands for the amount of buildings within a kilometer of a building averaged over all buildings in the municipality. A low or very low urbanity means an environmental address density of 1000 to 500 or less than 500 buildings respectively. To compare a cannabis nursery with other buildings, the average temperature of the location of the cannabis nursery over the six months before discovery by the police was measured. Then the average temperature of the buildings in the surrounding area is measured. At the end the temperature of the cannabis nursery was compared to the average temperature of the surrounding buildings. Then, based on this, the application could make mark buildings as suspicious when they are that much hotter than their surroundings.

An analysis was carried out on 103 cannabis nurseries in municipalities with low or very low urbanity. The comparison area was set to a square of a hundred meters in all directions around each cannabis nursery, for a total area of 200 by 200 meters. On average, there were 129 buildings in the comparison area. Surprisingly, the temperature difference between the cannabis nurseries and their surroundings was negative, the cannabis nurseries in the dataset were on average 0.08°C colder than their environment. This would make it impossible to find cannabis nurseries by comparing building temperatures to the temperatures of surrounding buildings. To assess the extent to which these results are driven by the size of the comparison area and/or the urbanity level, we repeated the analysis for different levels of both.

Results

In table 4 the results of these analyses are displayed, which will be explained below. In the first place a variation in the size of the comparison area is made. The lower amount of entries (cannabis nurseries) for larger comparison areas within the low and very low urbanity was not intentional. Rather, the number of entries is lower because the application would discard an entry whenever erroneous data was found in a building, which happened more often if more neighboring buildings were included in the analysis. As can be seen, the differences in temperature between the cannabis nurseries and the buildings in their surroundings in small comparison areas (100mx100m) and larger comparison areas (200mx200m) are both negative (-0.01°C and -0.08°C respectively). An illustration of the different comparison areas can be found in figure 4. Looking only at municipalities with very low urbanity the temperature difference was 0.02°C, 0.10°C and 0.12°C for respectively the 100mx100m, 200mx200m and 500mx500m conditions. Although these differences are positive and larger, especially with a larger comparison area, they were found to be not significant ($p=0.78$, $p=0.60$ and $p=0.63$ respectively) using a one-sided t-test. In other words, based on this analysis there is no evidence that cannabis nurseries in municipalities with very low urbanity have a higher temperature than buildings in their surroundings.

Average temperature	Temperature difference	P-value	Number of entries	Comparison area	Notes
17.88°C	-0.01°C	-	168	100mx100m	Municipalities with low and very low urbanity.
19.48°C	-0.08°C	-	103	200mx200m	Municipalities with low and very low urbanity.
17.61	0,07	0,41	78	500mx500m	Municipalities with low and very low urbanity.
17.67°C	0.02°C	0.78	10	100mx100m	Only municipalities with very low urbanity.
17.67°C	0.10°C	0.60	10	200mx200m	Only municipalities with very low urbanity.
17.67°C	0.12°C	0.63	10	500mx500m	Only municipalities with very low urbanity.
17.15°C	-0.11°C	-	36	100mx100m	Only buildings with few neighboring buildings were selected (6.14 neighbors on average).
15.58°C	-0.04°C	-	43	100mx100m	Only buildings with a surface area of over 900 were selected (the average surface area was 4256 m^2).
8.29°C	0.03°C	0.15	148	200mx200m	Only the months October to March were used in the analysis.

Table 4, A comparison of the temperature of known cannabis nurseries with buildings in their surroundings.

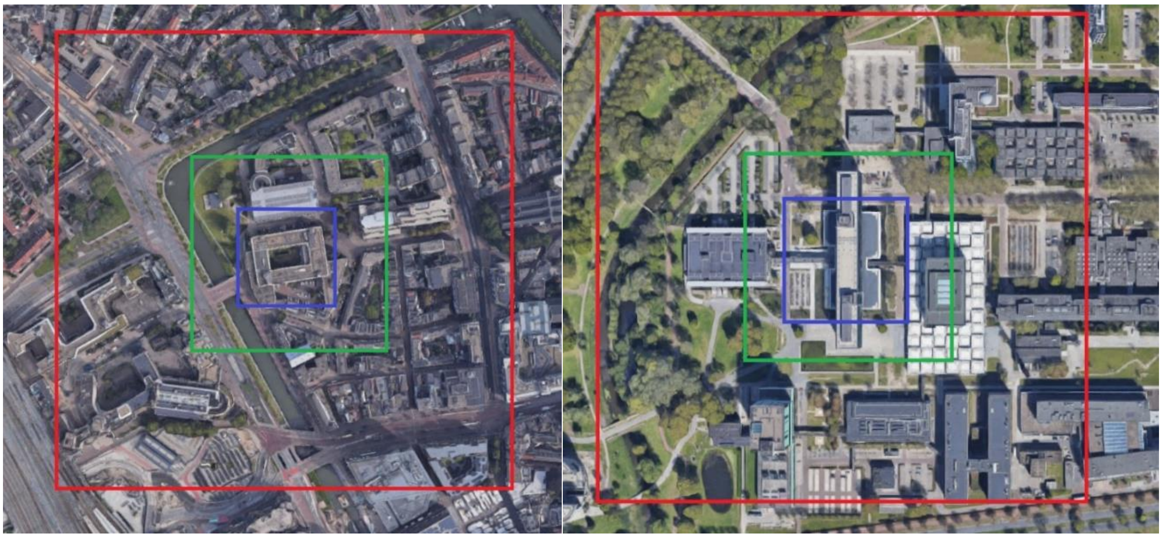


Figure X, an overview of the different comparison areas, centered around the center of the TU/e Atlas building and the Politie Bureau Kroonstraat building respectively. The blue area is the 100mx100m area, the green area is the 200mx200m area and the red area is the 500mx500m comparison area. Images taken from Google maps.

The possibility was considered that other factors were influencing the temperature measurements of the cannabis nurseries and surrounding buildings. First of all it was possible that other, unusually hot buildings in the surrounding area of a cannabis nursery were influencing the measurements. To minimize the occurrence of this possibility an analysis was done only on cannabis nurseries with few neighbors. Based on this analysis, cannabis nurseries were on average 0.11°C colder than their surroundings, again making the discovery of new cannabis nurseries based on this analysis impossible.

Another possibility was that inaccurate temperature measurements were hiding an actual temperature difference between cannabis nurseries and other buildings. Two ways to correct for this in the analysis were considered. First off all, the effect of buildings' surface area was investigated. It could be possible that the temperature measurement of one pixel (30m by 30m) of buildings with a small surface area measures a lot of the surrounding ground, with a lower temperature, and little of the roof, with a higher temperature. To correct for this possibility an analysis was done with only buildings with a surface area of 900m2, the size of a Landsat 8 pixel, or more. In this analysis, cannabis nurseries were again colder than buildings in their surroundings, by 0.04°C.

Finally, the time of the year was taken into account. If a lot of measurements were done during the warmer months of the year, that means summer, late spring and early autumn, the high outside temperature might obscure the buildings' temperature measurements. To prevent this kind of measurement inaccuracies, an analysis was done in which only temperature measurements from the months October to March were included. For each cannabis nursery the most recent set of these months from the point of discovery was used in analysis. This analysis did result in a positive temperature difference, cannabis nurseries were 0.03°C warmer than buildings in their surroundings. However, using a one sided t-test, the difference was not significant ($p=0.15$), meaning that this analysis provides no evidence that cannabis nurseries are on average hotter than buildings in their surroundings during the months October to March. The results of these analyses can also be found in table 4.

Even with these additional analyses, it is still possible that there exists a real temperature difference between cannabis nurseries and buildings in their surroundings, which could not be discovered. One reason could be that the temperature measurements of Landsat 8 are not accurate enough. Another reason could be that the sample size of cannabis nurseries is too low, especially for the analysis with only cannabis nurseries in municipalities with very low urbanity, since that analysis only had a sample size of ten locations. To complement the other analyses, it was also investigated if the results could be used if the temperature differences were significant. For this comparison, the average temperature of a piece of randomly chosen piece of rural area was measured. The analysis included 303 buildings from the rural area to the south of Lelystad Airport which had an average temperature of 19.40°C as measured over 18 months. The highest temperature difference found in the aforementioned analyses was 0.12°C. If this is the true temperature difference between cannabis nurseries and normal buildings, the algorithm could look for buildings that are 0.12°C hotter than buildings in their surroundings. Since the buildings are all part of the same area, we can simply check which buildings are hotter than 19.52°C and see if this is a useful selection criteria. In this analysis 47% (143) of the buildings were hotter than 19.52°C, making it unlikely that this is a useful selection criteria.

Finally, some analyses were considered but in the end could not be done. First of all, an analysis that takes the amount of cannabis plants found in a cannabis nursery into account, was considered. After all, cannabis nurseries with a low number of plants might produce too little heat for the difference to be measurable. However, the amount of plants was not included frequently enough in the RIEC-MN dataset for this analysis to be possible. Secondly, as an alternative method to detect suspicious buildings, the application could search for buildings that have a temperature comparable to other buildings even when they should not according to their function. If, for example, a building that is empty according to the BAG shows a clearly raised temperature, that would be a reason for suspicion. The advantage of this approach is that it works even when no temperature difference can be found between cannabis nurseries and normal buildings. However, too few empty buildings (none in a test sample of over 50000 buildings), as indicated by the BAG, exist for this analysis to be possible.

Discussion

Conclusion

The goal of this thesis was to investigate whether it was possible to use satellite imagery to detect subversive drug criminal activity and how such a technology could be best introduced by the RIEC-MN. To answer this question first the most promising type of satellite imagery has to be selected, both in terms of what was technologically possible to create and what was useful for the RIEC-MN. To this end a literature study was conducted and interviews were held with employees of the RIEC-MN and experts on satellite imagery. It was concluded that the detection of drugs labs in rural areas through infrared satellite imagery was the most promising option. Based on this, the next research question focused on how infrared satellite imagery could be used to detect possible drugs labs in rural areas. The main part of the project consisted of the development of an application that could effectively measure the temperature of buildings. At the end the application is able to read out Landsat 8 infrared imagery and calculate the temperature of a building. These data are connected to building data such as location, size and purpose from the BAG and KvK. Using the application, a user can select an area and a time frame and get building temperature data as a csv file. The data can also be visualized for the whole dataset or for individual buildings. In next the step, a dataset of discovered cannabis nurseries of the RIEC-MN was used to test the application. The temperature of existing cannabis nurseries was compared to regular buildings in their surroundings, in the expectation that the calculated temperature difference could be used to detect new cannabis nurseries. However, no significant temperature difference was found, even when correcting for various variables that could explain the lack of temperature difference. Without a temperature difference between cannabis nurseries and other buildings it is not possible to detect cannabis nurseries using infrared satellite imagery. Various reasons for the lack of temperature difference will be discussed below as well as the limitations of this thesis. Finally, recommendations for the RIEC-MN and for future research will be given.

Pre-study

As mentioned before, at the start of the project interviews were held to gather information about satellite imagery, drug criminality in rural areas and the needs of the RIEC-MN in that regard. Although the interviews did provide information and direction for the start of the project, there were several ways in which the interviews might have been improved. First of all, the interviews could have been done in a more formal way. Only notes were taken in this study, no recordings or transcriptions. This would have made the conclusions drawn based on the interviews more precise and more reproducible. It is possible that a more formal set-up of the interviews would also have made a more careful selection of interviewees possible, since some respondents had the same expertise. Besides the order in which the interviews took place may not have been optimal. However, since the exact expertise of the interviewees was not known beforehand and the planning of the interviews also depended on their schedules, the schedule of interviews was difficult to change.

Process

The most important decision made during the project was the decision how satellite imagery was used in the application. It was chosen to make an application based on infrared satellite imagery and look at temperature differences in buildings. At the moment of the decision, it was assumed that the detection of open-air cannabis cultivation and the detection of suspicious buildings through infrared satellite imagery were both feasible options. In hindsight an application based on infrared satellite imagery seemed not an optimal decision for the RIEC-MN and for this thesis because with the satellite imagery available it does not appear to be possible to differentiate between the temperature of drugs labs and normal buildings. The other option, namely detection of open-air cannabis cultivation, could have resulted in an application more useable for the RIEC-MN. The false assumption that drugs labs have a higher temperature than other buildings also caused a lot of work been done concerning refinement of the application, that later seemed not relevant. Although a lot of the work on the application was still necessary for the testing the application, there are still features that have no or little value now that the application cannot differentiate between drugs labs and other buildings. If the project had been focused earlier on finding out if it is possible to detect drugs labs with infrared satellite imagery, testing could have been done earlier and some time would have been saved.

Originally, it was planned to hold interview(s) with RIEC-MN employees to ensure that the application would be optimally useable by the RIEC-MN in the future. Because the application was unable to find a temperature difference, it will not be used by the RIEC-MN in its current form. Consequently, no usability interviews with RIEC-MN employees were held.

Results

In the results section an analysis was done by comparing the temperature of cannabis nurseries found by the police in the past years to the buildings surrounding them. No analysis on synthetic drugs labs was done. This choice was made because, although the manufacturing processes of synthetic drugs labs produce heat, it was assumed that they do not produce as much heat as cannabis nurseries and not as consistently. Measuring the temperature of traced cannabis nurseries in relation to other buildings is a good way to detect a temperature difference that could be used to trace other possible cannabis nurseries, provide that the temperature difference is large enough. However, no such positive temperature difference was found in the analysis.

Some possible explanations for this result were considered and tested in the results section, such as: varying in the size of the comparison area, the urbanity and the number of comparison buildings, testing only buildings with a high surface area and testing only during the colder months of the year. The conclusion based on these analyses remained the same, no positive significant temperature difference was found. It is still possible that an actual temperature difference exists that cannot be measured by the analysis for example because the reported cannabis nurseries might be too small to have a notable influence on the temperature of the building. Unfortunately, there was not enough information about the number of plants in the cannabis nurseries in the RIEC-MN dataset to check this explanation. Another explanation is that the infrared measurements from Landsat 8 are not accurate enough to detect temperature differences in individual buildings. If this is the case, it could either be a consequence of the 30m by 30m pixels (resampled from 100m by 100m) being too big to reliable measure a single building, or it could be a consequence of the temperature measurement of a pixel being too inaccurate for this purpose. The latter is less probable, because the Landsat 8 per pixel temperature measurements are fairly accurate. In the study on which the algorithm to calculate the LST from Landsat 8 data is based (Ermida, Soares, Mantas, Göttsche, Trigo, 2020) average inaccuracies of 0.3°C are reported for Landsat 8. Given that the temperature inaccuracy is random noise for the purpose of the analysis and 0.3°C is relatively small compared to the variation in building temperatures and the practical significant temperature (see below), this temperature inaccuracy is unlikely to influence the analysis. At the same time, Landsat 8 measures infrared with pixels of 100m by 100m pixels which are resampled to 30m by 30m pixels using the cubic convolution method (Acharya & Yang, 2015). Although certainly more suited for the purpose of measuring the temperature of buildings than the original 100m by 100m pixels, cubic convolution does likely introduce some error into individual pixels (Keys, 1981).

Finally, another possible explanation could be that cannabis nurseries do not have a higher temperature than other buildings at all. While cannabis plants do require higher temperatures to grow than the average building temperature, this might not have an effect on the roof temperature, for example because of good isolation or because the cannabis nursery is not located directly under the roof. Given that it is relatively well known that the police looks for cannabis nurseries with heat detection, it is also possible that drug criminals have taken actions, such as cooling, to prevent a noticeable heat signature. The question of which of these explanation(s) is/are correct will be addressed in the recommendations for future research.

It is somewhat surprising that the police is able to detect cannabis nurseries using infrared scanners and other studies are able to make use of satellite imagery while this study is not able to. Although it is speculation, since the reason for the lack of temperature difference is unknown, the difference with other studies is likely the scale. For example, the paper on heat islands in cities (Kaplan, Avdan, Avdan, 2018) studies only the effect of temperature on the scale of city-blocks instead of buildings. Similarly, studies in other areas of satellite imagery also do not focus on objects smaller than the size of a single pixel. When the police looks for cannabis nurseries using infrared scanner they are not simply scanning the roofs of all buildings, they compare the heat signatures of buildings with that of their neighbors (Haran, Higgins, & Thomas, 2004, September). They also look for buildings with suspicious heat signatures such as an unusually hot cellar window. That precision cannot be matched using 30m by 30m satellite data.

Future research

Something that might impact future research in this area is the recent launch of the Landsat 9 satellite. To be precise, Landsat 9, the newest satellite in the Landsat series, was launched on 27-09-2021 and will become fully operational in January 2022. The instruments in Landsat 9 will address some minor issues that were found in Landsat 8 but will have the same accuracy and pixel size as Landsat 8 (Markham, Jenstrom, Masek, Dabney, Pedelty, Barsi & Montanaro, 2016). However, Landsat 8 will remain operational so that will mean that new data comes every eight days instead of every sixteen. The additional data will make it more likely to obtain a temperature measurement when looking at a short time span or improve the accuracy of averages of longer time spans.

One direction that is interesting for future research is to investigate what caused the lack of temperature difference in this study. The results of that study will give a good inclination if drugs lab detection through infrared imagery will be possible with better satellite data. The most obvious way to do this is to measure the temperature of the roof of a drugs lab at the moment that it is discovered by the police. This is less difficult than it may sound, the police force charged with dismantling a drugs lab (usually the LFO, National Facility Support Dismantling) could be asked to point a long range thermometer at the roof of a drugs lab. This would require the drugs lab to be active up to the moment of discovery. This temperature could be compared with the temperature of the roof of surrounding buildings or with the temperature of the roof of the drugs lab after it is dismantled. If there is a significant difference, it is at least theoretically possible for drugs labs to be detected with more advanced infrared satellite imagery. Should more advanced satellite imagery come available, the analysis as described in the results section can be repeated with small adaptations to the current application. Similarly, the application can be used by researchers interested in using infrared satellite imagery for the measurement of temperature of surfaces such as neighborhoods, parks or cities. Currently the application uses only a single measurement at the center of the building, but for these purposes the application should be adjusted to take all pixels in the object into account.

Recommendations and further research RIEC-MN

The RIEC-MN intends for this thesis to be part of a larger body of research on the application of satellite imagery. Next to drugs lab detection through infrared satellite imagery, the topics that will be investigated are the detection of outdoor cannabis cultivation through satellite imagery, the detection of unusual vegetation in water and change detection through full color satellite imagery.

The detection of drugs labs through infrared satellite imagery seems not possible with the current technology. In the results section an analysis was also done assuming the temperature difference of 0.12°C was statistically significant, to see if this difference was practically significant. This was not the case, almost half of the buildings were as hot or hotter than the average temperature plus 0.12°C. If the RIEC-MN would attempt to use the application to trace new cannabis nurseries, the amount of buildings marked suspicious would be far too high for a real drugs lab to be found among the false positives. However, for future studies it is useful to know when a temperature difference is large enough to be practically interesting, at least with Landsat 8 data. To that end, the above analysis was repeated on the same area of countryside (the area to the south of Lelystad Airport) while constantly increasing the temperature difference that was added to the average. Assuming there are no drugs labs in this area, this analysis gives an indication of the amount of false positives that would be found should a real analysis be ran using the same data. At a temperature increase of 1.9°C only 5% (15) of the buildings were left. Only 1% (3) buildings were 2.6°C hotter than average and no buildings had a temperature 3°C or more hotter than average. Any future attempt to detect drugs labs with Landsat 8 infrared imagery should take into account that when the distinction between drugs labs and normal buildings is made on a temperature difference of 2.6°C or less, the amount of false positives will be more than 1% of the number of buildings and might be too large for the analysis to be of practical use. Because a temperature difference of more than 2.6°C is unlikely, even if further analysis of more drugs labs would find a significant temperature difference between cannabis nurseries and other buildings, it is improbable that a practically significant difference will be found with Landsat 8 data. It is interesting to study which of the abovementioned explanations are correct, as well as address the limitations of this study, but for the RIEC-MN, to detect drugs criminality in rural areas, infrared satellite imagery does not seem a promising option.

The detection of outdoor cannabis cultivation was already mentioned in the pre-study and background and previous research section as the other potential direction for the project. As already mentioned, this seems like a promising option for the RIEC-MN to investigate. Earlier studies showed that it was possible to distinguish cannabis from other vegetation.

The detection of unusual vegetation in water has not been investigated in the pre-study or background and previous research sections, but some related options have been investigated. The idea behind detecting unusual vegetation in water is that the vegetation might give an indication of the chemicals in the water. Different plants thrive in different chemical environments and a sudden die-off or bloom of vegetation can indicate a new influx of chemicals. Using this information it might be possible to detect drugs waste dumps or drugs labs that are continuedly dumping drugs waste in the environment. However, in practice there are some difficulties that need to be considered. First of all, the available resolution might play a role here too. Sentinel 2 is a open source satellite with quite some of its bands focused on monitoring vegetation. It has a resolution of 10m by 10m which means that if the body of water is a ditch or a pond, it is likely a significant part of the pixel is capturing things that are not vegetation in water. On the other hand, if the body of water is large enough that its vegetation can be measured by satellite, the effect of dumping some chemicals in it might be too diluted to detect. Secondly, the changes in vegetation caused by dumped chemicals are likely hard to distinguish from other changes in vegetation. One of the experts from the pre-study worked on a similar project with as goal investigating the monitoring of poisonous heavy metals in surface water through their effect on the surrounding vegetation. He stated that it was impossible to distinguish the effect of the metals from natural variation in vegetation. A similar problem could occur here, where even if accurate measurements of vegetation in water are possible, the natural variation in vegetation causes too many false positives for an analysis to be useful. The RIEC-MN is recommended to study these limitations before starting a full project on detecting unusual vegetation in water.

Change detection is another option that the RIEC-MN intends to investigate to trace drugs criminality. Change detection through full color satellite images seems theoretically possible, but difficult. First of all, an algorithm attempting to do this should be able to differentiate between real changes to buildings and property and the changes caused by image noise, satellite position and contextual factors like changing weather, changing seasons or accidentally captured, non-permanent changes such as an inflatable pool or clothing hung out to dry. Secondly the algorithm should be able to distinguish legal or non-suspicious changes from changes indicative of a drugs lab. As indicated in the pre-study, it can be difficult to find suspicious behavior based on the (change of) characteristics of buildings found in color satellite images. The focus for an application could be to look for illegal building activity. This could be done relatively easily by training a neural net on legal, new buildings. Then after the training neural net can be used to detect any new building activity and use municipal data to find out if this building activity is illegally. It does not provide direct evidence of a drugs lab, but illegal building activities are an indicator of a drugs lab. Moreover, this information is valuable for the municipality.

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