Gaining insight into the spatial and temporal characteristics in the Netherlands using the Visible Infrared Imaging Radiometer Suite (VIIRS) active fire dataset

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Abstract

The fire seasons have globally lengthened over the last 50 years and the effected surface areas has double. It is driven by climate warming may increase occurrences of fire into low historically low risks areas, such as northern temperate Europe. The Netherlands is one of these countries where fire risk and occurrences may increase. The Visible Infrared Imaging Radiometer Suite (VIIRS) active fire algorithm can be used to gain insight into the spatial and temporal characteristics of fires in the Netherlands. Landcover is associated with Corine Land Cover (CLC) data to gain insight what type of fires occur in the Netherlands and gain insight into the fire season with data between January 2013 and December 2020. 206 pixels were identified and classified. There are 3 major types of fire pixels heath (39.8%), peat (31.6%) and forest (25.7%). The occurrence of fires peak in spring, but forest fire has a small peak mid-summer. 77.7% of the pixels are in natural designated areas and 95% of the fires are within 1400 meters of human infrastructure with 80% even within 500 meters. The western-central European high-pressure area and the decrease of precipitation in the winter cause that soil moisture is decreased, and vegetation has not been restored in spring. These causes with a higher risk of fire near infrastructure areas cause that most fires pixels occurred in the early spring. These characteristics can be used by policy makers on how natural designated areas are influenced by fires and is a useful benchmark on how fires develop in the future in the Netherlands. In future research, the monitoring of human activity surrounding these natural designated areas can give more insight into the occurrences of fire

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Contents

1. Introduction

Wildfires play a vital role in various ecosystem, such as savannahs and boreal forests. They influence the development and sustainability of these and various ecosystems. Before the Anthropocene, the main cause of wildfires natural ignition has been lighting [1], but currently the majority of fires are directly or indirectly ignited through human activities. A major contributor of direct human ignition is the clearing of land for agriculture activity and pasture. People also actively suppress fires to mitigate and prevent negative impacts on climate, air pollution and protection for the regional population. The prevention measurements can cause accumulation of fuels in fire sensitive climates, which in turn can result in intense wildfires. All these causes and policies, have lead that agricultural land has expanded in savannah regions and active fire suppression have led to reductions of fires in the 2000s [2].

There are also indications and observations that fire seasons are globally lengthened and the fire affected surface area is doubled [3]. Fire risk is increasing and will keep rising with continuation of global warming [4]. These changes can introduce fire regimes and fire seasons into currently low fire risk areas. The prediction is that climate change is going to make the duration of fire seasons longer, the frequency of fires increasing [5] and the risk of the fire is going to be higher in the 21th century. These climatological effects could be amplified by the changes in the local landcover as a response to the warmer and drier climate [6].

All these effects and consequences are going to impact the local population, environment, political stability in its surroundings and economic situation [7,8]. Various health issues related to respiratory systems have been related to forest fires and fires have already effected the local population for a short or long period of time where fires were prominent [9,10]. These fires have also resulted before in riots, habitat loss and damage and properties [7,11].

In Europe, around 70% of the fires and 85% of the burned surface area is in the Mediterranean region. While wildfires and the consequences have been extensively researched in the Mediterranean area [8,12,13], global change is not only going to affect Southern Europe. The risk of fire is predicted to increase in currently wetter climates in temperate and northern Europe [6]. Therefore, it is important to get more insight about how these wildfires are burning, how these fire regimes have developed over the last decade and on which vegetation type these fires mostly have burned in a temperate European country.

The Netherlands is one of the countries in Western Europe, where an increase in risk of fires is predicted if global warming is going to continue [14]. The country has various unique spatial and population characteristics that could greatly impact how wildfires start. These characteristics give insight into how policy and population influence current and future wildfires. The spatial policy of this country has a rich history in spatial planning and in general water management. It has led to improved Dutch waterwork and the introduction various spatial policies to stimulate economic growth in the 20th century. These results of these policies resulted in a highly fragmented landscape and high density transport infrastructure [15–17]. Another characteristic of the Netherlands is that it has the highest population density per square kilometre in Europe with 513 people / km^{2} [17].

Besides the countries spatial policy, the European Union (EU) has impacted various spatial zones through a policy named the Bird and Habitats directives. The directives indicate that several designated landscapes are chosen to preserve the European biodiversity. These areas are found all over the EU and are part of a network, which named the Natura 2000 network. The implementation of these areas in the Netherlands were done by local and regional local instruments [18] and has contributed to the current Dutch fragmented landscape.

The fragmented landscape and the various small specific natural areas may affect or have already affected the current and future fire regimes of the Netherlands. Furthermore there have already been various indications about that most forest fires are indirectly/directly caused by human agents [8] and that the chance of wildfire is increased near infrastructure [12]. With the influence of human activity on wildfires and the natural areas near human activity and infrastructure, the amount of wildfires can be increasing in the Natura 2000 areas. The consequences of the increased wildfire can have ecological benefits or ecological damage in these areas.

Spatial and temporal information about these fire regimes can be useful for spatial policy, human health, and biodiversity. Governmental institutes can use the temporal and spatial information about the current fire regime to prevent ecological damage and effected human health is reduced [7,11]. Furthermore, it can be used as a starting point on how the fires are influenced by the regional effects of climate change.

This study is going to provide new insights about the temporal aspect of fires in heavily human influenced landscape, such as when the most fires are burning for the last decade and which years were most wildfires were burning. The spatial aspect is also researched with information in which natural areas were the fires burning, and what was the most effected land cover type by the fires. The combination of temporal and spatial information about these fires is going to give information about the simple question when, where and what the fires have burned.

2. Research Method

2.1 Data

2.1.1 Research Area

The Netherlands is the research area. The spatial dataset about the country is downloaded from a service, named the Public Services on the Map (NL: Publieke Dienstverlening op de Kaart; PDOK). This is an open data platform where people find various governmental related spatial datasets about the Netherlands and frequently updated. From the PDOK, the borders for the Netherlands is downloaded from https://www.pdok.nl/geo-services/-/article/administratieve-eenheden-inspire-geharmoniseerd (last accessed: 04-05-2020). Information about the infrastructure is also downloaded from PDOK downloaded from the national road file (Nationaal Wegen bestand; NWB). This file contains information about the Dutch infrastructure. It can been found from https://www.pdok.nl/introductie/-/article/nationaal-wegen-bestand-nwb- (last accessed: 17-08-2020).

2.1.2 Fire dataset

Various satellites observe active fires around the world. One of these satellites is the Suomi National Polar-orbiting Partnership (S-NPP), which has an instrument named the Visible Infrared Imaging Radiometer Suite (VIIRS).

The satellite S-NPP orbits around the earth at an altitude of 829 km and crosses the equator twice once when ascending around 13:30 (Greenwich time) and once descending around (01:30). VIIRS-instrument measures the surface of the earth with 22 different spectral bands and has a swath width of 3060 km.

The instrument has 16 moderate resolution bands (M-bands), 5 imaging resolution bands (I-bands) and one panchromatic day night band (DNB). The DNB-and M-bands have a resolution of 750 meter, while the I-bands have a resolution of 375 meter. With an unique approach of pixel aggregation, VIIRS pixels are observed with a pixel size at 375m or 750 meter [21].

An algorithm for VIIRS has been developed to find active fire from the source data [22]. The most important input for this algorithm is the data from the I4 sensor. This sensor measures the middle infrared (MIR) spectrum between 3.55 - 3.93 µm. Temperature of the electromagnetic radiation indicates if there is at time of measurement is an active fire or not. The other sensors from the I-bands are used to verify the active fire and quality of the measurement. With the help of the DNB, fires are also detected at day and night. The dataset is acquired for each month between 2012-01 and 2020-12 and saved in an ASCII file with the file name VNP14MLIMG. The aggregation scheme keeps the resolution of the dataset at 375 m and has a low commission error (< 1.2%). The detection of these firepixels by the algorithm varies between different land cover types, the fire sizes and time span of the observed fires. It can detect smaller (with a minimum 10 m^2 at night time) fires and is improved on the detection of boreal fires and savannah fires but has a lower performance against agricultural fires. Overall, the dataset is suited for the detection of natural active fires [23] and therefore used to get information wildfires in natural areas in the Netherlands.

The files of the dataset is downloaded from *ftp://fuoco.geog.umd.edu/VIIRS/VNP14IMGML (last accessed in May 2021)*. The data cover a period from 01-2012 up to 12-2020. More detailed information about the fire observation datasets and surrounding research are found on https://modis-fire.umd.edu/.

2.1.3 Land cover datasets

The Corine Land Cover (CLC) is the dataset, which is used to identify and specify the kind of wildfire. The dataset deducts the land cover with satellite date of the Sentinel 2 and Landsat-8. The Sentinels-2 is part of the European earth observation program that is used to acquire high resolution data about the land surface and identifying natural hazards in Europe [24]. The Landsat-8 is part of the Landsat-program and has the same purpose as the Sentinel-2 satellite [25]. The Sentinel-2 provides the main dataset, while the data of the Landsat-8 is used for to fill in the gaps. The used CLC 2018 dataset has been developed between 2017 to 2018. The datasets have both an equal and greater 85% thematic accuracy with a minimum mapping unit of the polygon of 25 ha. The minimum pixel size is 100 meters. Furthermore, all changes that are greater than 5 ha are mapped and updated in the dataset [26].

The dataset from 2018 are used and are downloaded from *https://land.copernicus.eu/pan-european/corine-land-cover/clc2018?tab=download* (last accessed in May 2020).

2.1.4 Natura 2000 and National parks

The European Union (EU) has developed a program to protect endangered species to ensure, sustain and increase European biodiversity through the Natura 2000 network. 162 of these areas are in the Netherland. It supports the biological diversity in various landscapes and protects breeding areas for various specious. The preservation of the natural processes and habitats strategies [27] in these areas have influenced the spatial distribution of wildfires in the Netherlands. The relationship between the Natura 2000 and the wildfire is that the preservation of the habitats could result in specific land cover which could be affected affect the frequency and size of these wildfires. With the quantification of fire pixels in these areas, it could give insight how the fire regime impacts the various landscapes and habitats and how it can be prevented.

The shapefile of this areas is downloaded from PDOK (*last accessed in September 2020)* as the administrative borders.

2.2 Overview of the methods

Two different methods, which are visualized in flowcharts (see figure 1) have been developed for this research. The first method is for acquiring the data from the VNL14ML, CLC-raster data and administrative borders of the Netherlands. For each method, there will be given an overview how and why each step in the flow chart has an impact on the filtering of active fires.

The data is inserted into a PostGreSQL database (version 13.2). PostGreSQL is an open source relational database engine (https://www.postgresql.org/) and is used in combination with the PostGIS plugin. The PostGIS database extender is extension for PostGreSQL, which helps to save raster and vector data is central location and easier to filter related pixels.

The data inserting and analysis is done with Python 3.9.2. There are various libraries used to calculate the geospatial characteristics of the fire pixel. They are citated in the requirements file in the github repository.

The scripts that are developed for parsing and analysing the VIIRS, CLC, and PDOK files can be found on *https://github.com/CUniversityaccount/ForestFireNetherlands*.

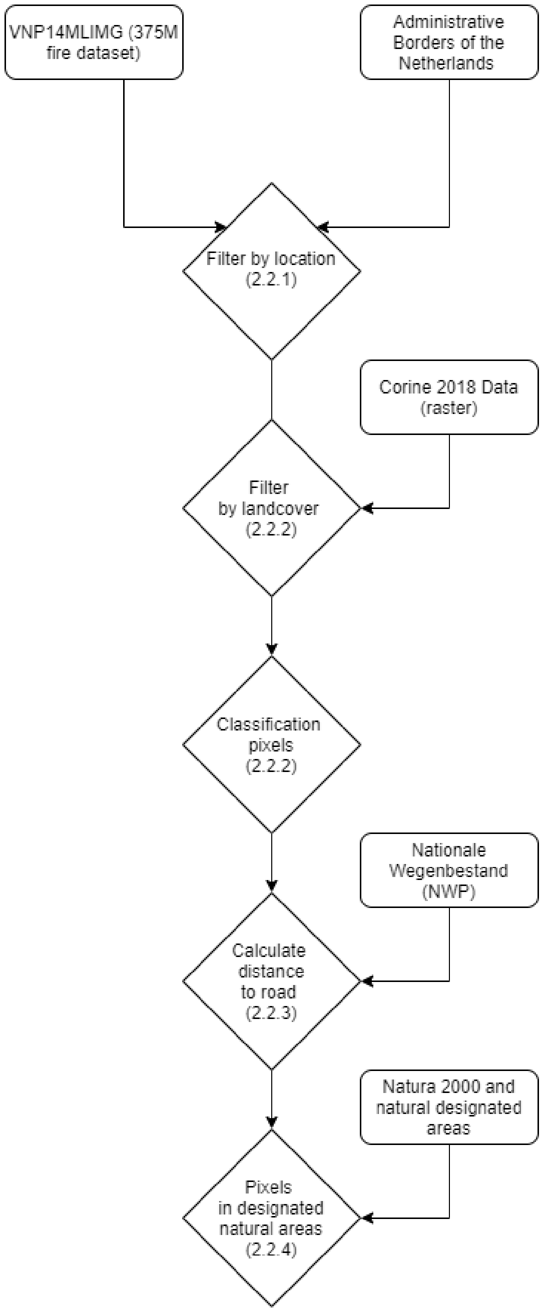

Figure 1 Flowchart on how the fire pixels derived from the active fire algorithm are filtered and classified based on CLC pixels

The general overview of the method for acquiring the data can be seen in figure 1. The numbers between the brackets are the corresponding sections.

2.2.1 Filtering of the VIIRS Fire pixels based on location

The VIIRS pixels are filtered by the location of the centre of the pixels. When a pixel is not within the administrative borders of the Netherlands, then it is filtered out.

After the non-relevant pixels are filtered out, the size of the pixel is determined. The size of the pixel is deducted from the horizontal position, whereby the zero point the nadir is. The change in angle, observation distance and curvature of the earth cause difference in pixels sizes. The general effect is how greater the distance is from nadir, how bigger the pixel. VIIRS compensates the deformation of its pixels with multiple bands and the aggregation scheme. The instrument can therefore keep the pixel size 375 meter up to the 960^{th} observation. After 960^{th} observation, the aggregations scheme and sensors can only observe pixels with a size of 750 meter [21]. This effect is applied to the filtered pixels. All observations whereby the observation count is lower than 960 gets a pixel size 375 and after this observation it gets a pixel size of 750 meter. These values are already indicated in the dataset.

2.2.2 Filter and classification of the fire pixels

The VIIRS active fire algorithm [22] classifies the type of anomaly temperature in the pixel. The types of thermal anomalies are vegetation (indicated with a 0), active volcano (1), other static land source (2) or an offshore detection (3). In this study, the classification is focused on natural fires and is categorized around the type of landcover. Therefore, all the pixels classified as a vegetational fire are used.

The data also have a confidence attribute named *conf*. This confidence level of the observed fire pixel and can be low, nominal and high. The pixels with a low confidence filtered out to minimize false positives.

The classification by landcover has two purposes. It filters out the pixels whereby the pixel has not burned or cannot be deducted it has burned on natural land covers and the classification of natural type of the pixel. The 2018 CLC-dataset is developed in 2017-2018 and has been used to classify the VIIRS pixels.

CLC datasets has a three levels hierarchy structure and is represented in the landcover pixel as three number code (head-class, sub-class, landcover) [28].

The following logic rules have been defined to filter pixels out that do not have affected natural landcover:

- A VIIRS pixel does not have a single industrial or urban pixel (CLC pixels between 0 and 200). Hereby, it is unclear if the fire is natural. The fire could have happened in an urban area or has been mistakenly identified as fire. The source of the fire is unknown and cannot with current method be deducted.
- A VIIRS pixel cannot burn above water, so fire pixels with only waterbodies as landcover are filtered (the CLC values are between 500 and 600).
- A VIIRS pixel is not a natural fire if 50% or more of the CLC pixels are from agricultural origin (CLC values between 200 and 300. This has the same principle as the first point, whereby the source of the fire is unclear and therefore filtered out.

The rest pixels are going to be identified by the most dominant CLC-type. Dominant is here the most abundant landcover range. If the natural landcover cannot be identified, for example the amount of effected but different landcover are equal, the fire pixel gets the classification combined nature. The types and the CLC value ranges are set out in table 1:

Table 1 The fire types with their landcover ranges that are needed to classify each fire pixel.

Classification	CLC ranges
Forest	310 < CLC-pixel value < 320
Heath	320 < CLC-pixel value < 330
Dune	CLC-pixel value == 331
Peat	410 < CLC-pixel value < 420
Combined Nature	300 < CLC-pixel value < 332

2.2.3 Measuring the distance between the fire pixel and infrastructure

The distance between the Dutch infrastructure (NWB) and the classified pixels are calculated with the help of the program QGIS with the NNJOIN plugin. There is no clear distinction between the characteristics of the road such as road activity, size of the road, and general use of the road. These characteristics of the roads cannot be determined or are available in the NWB file. It results in the smallest between the polygons which are in this case between the roads and the fire pixels. The source code of this plugin is found https://github.com/havatv/qgisnnjoinplugin.

2.2.4 Fires in natural designation areas

The quantification of pixels based on location is done with datasets about the geolocations of the Nature 2000 areas and natural parks. The pixels are counted when they are in a Natura 2000 or natural park. So, we get insight about how spatial policy decisions about designated natural areas has influenced the fire regimes in the Netherlands

3. Results

3.1 Spatial characteristics and observations

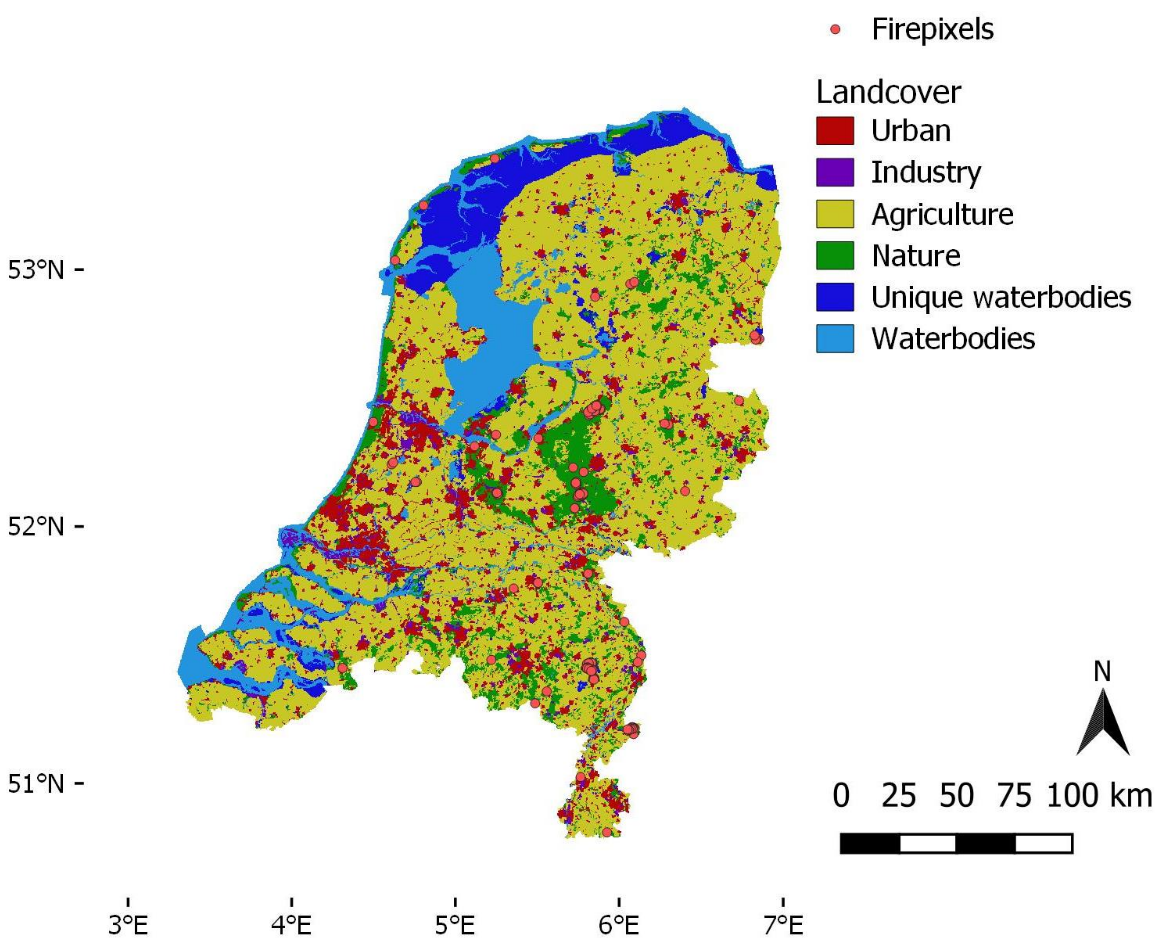

Figure 2 Spatial distribution of observed fire pixels between 2013 - 2020 in the Netherlands.

Figure 2 shows the spatial distribution of the 223 pixels. 41.7% of the fire pixels are observed in the central Netherlands. Around46.6 % of the pixels are in the south east. The rest is scattered around the country.

Most of these fires were classified as heath fires. The exact distribution of each fire type is seen in figure 3. The peat relatively are less common and forest fires are the least frequent of the major classes. For 3 pixels, it was not possible for the algorithm to classify the type of fire with the landcover. There was a single observation which was classified as dune, but following the definition in Corine Land Cover can also be contributed to heath. It indicates that heath has an increased risk to be ignited and is the landcover that influences the fire season in the Netherlands.

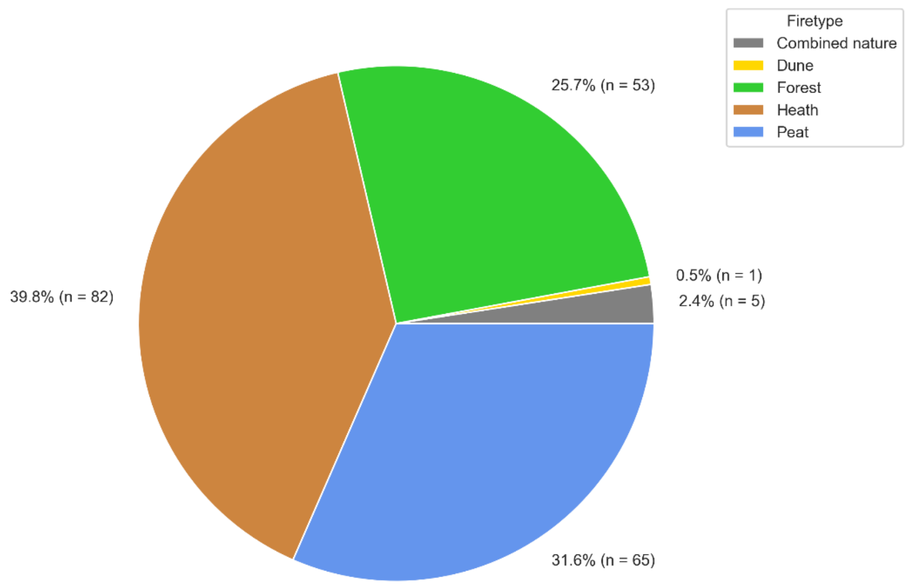

Figure 3 The distribution of fire pixels grouped by effected landcover by the fire pixel

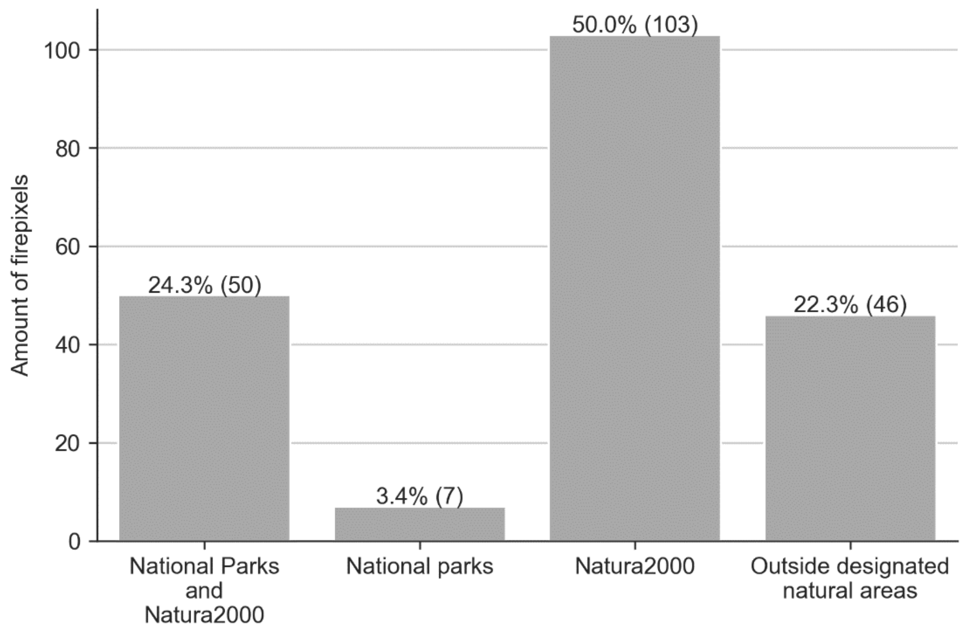

Figure 4 Distribution of fire pixels over the national parks, Natura200 and non-designated natural areas.

77.9% of thee pixels were burning within designated natural areas (see figure 4). The policy and spatial characteristics of the designated natural areas effect the occurrence of fire pixels and indicates that these areas have a higher risk in comparison against non-designated areas.

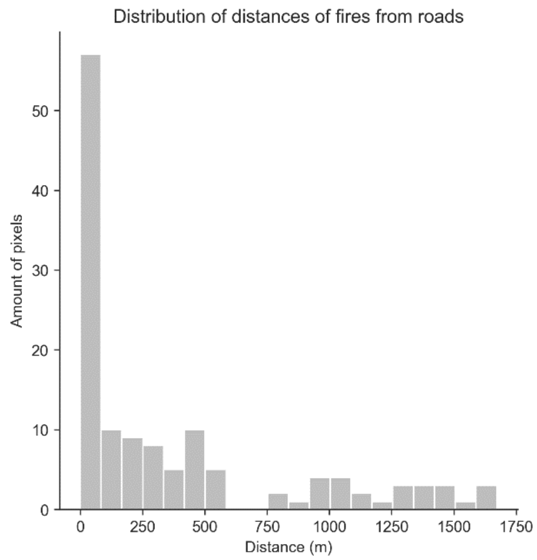

Figure 5 Histogram which shows the relative distance between a fire pixel and the Dutch infrastructure.

95% of the pixels were located less than 1.35 km from human infrastructure and most of these pixels (80%) were located within 500 meters of these roads (see figure 3). The occurrences of fire pixels in natural designated areas and the distance between the pixels and the infrastructure is possible explanation that these fires are caused by human activity.

<u>*3.2 Temporal characteristics and observations*</u>

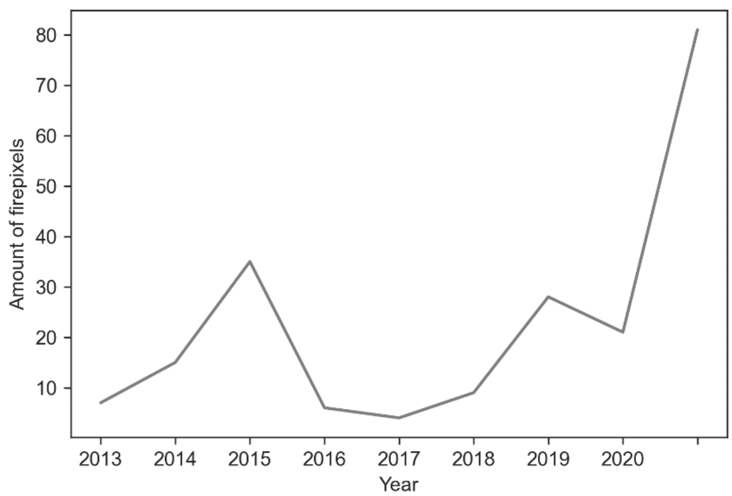

Figure 6 The amount of fire pixels per year.

The temporal plots are on yearly resolution and monthly resolution. There is a small peak in 2015 and for the last years it increased. The period is too short to state if the frequency of fires is increasing or decreasing. The fire in 2015 contributed a lot of heath fires pixels and in 2020, there were a lot of peat fire pixels observed. Both fires happened in April, so the monthly average is influenced by these outliers.

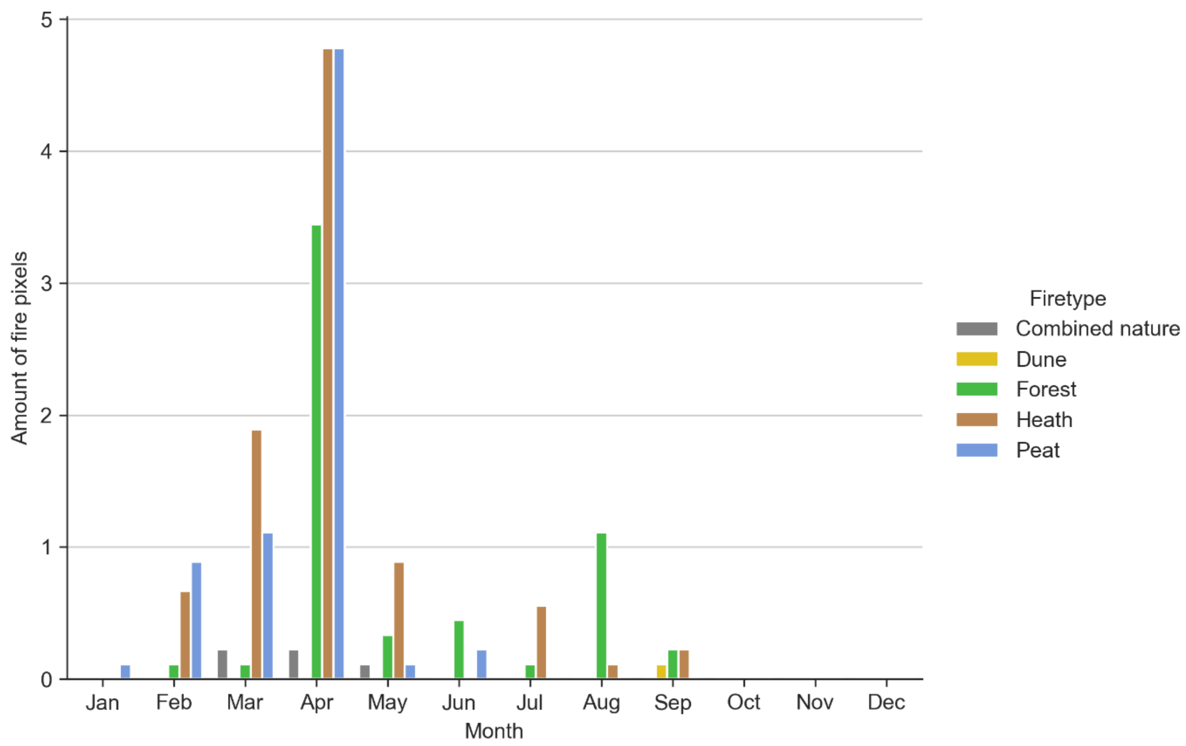

Figure 7 Average amount of observed fire pixels observed per month

Most fire pixels are observed in late winter and spring and lower rate in the summer (see figure 4 and 5). Each year has a fire in spring, but not in the summer. The most fire pixels were observed in 2020, whereby a fire at the Deurnese Peul happened and contribute a lot of peat fire pixels. When combining this information presented in figure 7. It shows that fire begin in February, it peaks in spring for the exception of forest fires and it fades out in the summer. Only for forest fires, it peaks in the late summer. The peak of heath fires in spring caused by the peak in April in 2014 and the peat fire pixels are mostly contributed by the Deurnese Peul fire. Nonetheless, it still indicates that most fire pixels are in occurring over spring and the amount of fire pixels is relatively small over the years.

4. Discussion

4.1 Limitations and uncertainties in the dataset

The dataset has several limitations in it that are linked with VIIRS. The influence of the limitation are seen in the results. Oliva and Schroeder [23] demonstrated that the identification of fires in grassland and heath have a higher commission error in comparison with other land cover types. The most effected landcover by these fires is heath. Therefore, some of the possible pixels could be false positives and dataset could give a slightly warped image.

The temporal resolution of the satellite cause that some active fires are not identified or observed. The VIIRS instrument has a 12 hour gap between each observation on a specific location [29]. Fires that were active in the 12-hour gap are not identified. Therefore, the dataset is slightly incomplete.

The location of the fire pixels is also difficult to determine. VIIRS can observe fires up to 25% of a Landsat-8 pixel (a spatial resolution of 30 meters) [22,23], but this cannot be calculated or deducted form given information of the fire pixel. The classification combined nature was introduced to identify these difficult distinguished type pixels. They cannot be used to gather information about the seasonal effects for the different fires. It causes that information is missing about the seasonal effect on the temporal and spatial distribution of fire pixels.

At least, the daily temporal resolution of the measurements, temporal timeframe of the research and the quantification in terms of fire pixels instead of fires shows and gives no clear indication about the size, number and the duration and activity of fires. These characteristics are important to get information about the duration and spatial characteristics, the cause and timing of the fire and potentially the impact on the local population and infrastructure, which are generally used in regional risk management.

Some fires are small in surface area and others were burning for a short time span, while other fires were burning for several days and were affecting large surface area. Therefore, the amount of detected fire pixels can be used to gain information about the generally effected area and landcover but not about the spatial and temporal characteristics of an individual fire.

4.2 Location of the fire

Nonetheless, the figures are showing various details and findings about the fire pixels location, effected landcover, seasonal influences and the cause of these fire pixels. As seen in figure 5, 77.7% of the pixels are within designated natural areas. The spatial policy of the European Union and Dutch government has influenced the fires in these regimes. The Natura 2000 are protected, as stated in the method, by the two directives. The spatial policy changes in these areas are rather difficult because [30] these spatial changes and policies in these areas need to be approved by the European Union [31]. The regional natural areas are governed by the provinces, but are still in development and researched in how this decentralized spatial policy has its effect on the natural spatial policy [32]. The explanation between the difference between fires in Natura 2000 and national parks could be explained.

4.3 Human influences

While abiotic and biotic factors are impacting the risk of fires, the key to finding the different components of the driving force behind the fire regime also is in the mapping and analysing human activity in the protected areas. As Pechony and Shindell [32] and Ganteaume *et al.*[8] have shown, higher population density increases the occurrences of wildfires. They observed that fire ignition and fire suppression will increase when the population density increase.

The low distance between a fire pixel and a road indicates are also relevant for gaining insight into the main driving force of fire in the Netherlands. Elewa [33] has stated that a higher density infrastructure is related to the frequency of wildfires in the Mediterranean. This observation was related that an higher density of infrastructure resulted in a higher fire frequency in the surrounding area [12]. While the Netherlands has a climate with a milder temperature and high amount precipitation [35], these observations are applied to this situation, because the country has one of the highest population densities in Europe [36], high density infrastructure [17] and most of the observed fire pixels are in a radius of less than 500 meter. The fire pixels are therefore caused direct and indirect influences of by the human activity.

4.4 Climatological influences

Dryness, precipitation, and evaporation are increasing and influencing the risk of fires in specified natural areas. Lower soil moisture is potentially caused by the evaporation and plant transpiration and the high-pressure zones around Western Europe in spring. The loss in evaporation is not made up with the precipitation and run-off from river systems and leads to lower soil moisture in the eastern and east southern Netherlands. The precipitation decrease in the summer, but the soil moisture decreases slightly is mostly maintained [38].

Another influence is the precipitation in the winter. A fire that happened April 2020 at the Deurnese Peul was researched and showed that the vegetation in the area had a low normalized difference vegetation index (NDVI). The vegetation had not recovered from the precipitation and colder temperatures in the winter and were therefore more vulnerable to ignition [39].

With decrease of soil moisture through plant transpiration, low precipitation in the winter and the low distance of human infrastructure, the risk of natural fires increases in spring. Mostly western southern Europe is affected by this, which partly explains why fires are concentrated in central and Southeast Netherlands, besides the policy surrounding the Netherlands.

Figure 7 shows also that heath and peat fires are peaking in the spring and fades out in the late summer. This is distorted by the peak of observed fire pixels in 2014 and 2020, but nonetheless the high-pressure zone in Western Europe in the spring and decrease in precipitation are important influences to explain about why these fire pixels are observed in the spring.

5. Conclusions

The VIIRS fire detection algorithm dataset [22] and the CLC-dataset [26] are used to gain insight into the spatiotemporal aspect about natural fires in human-centred landscapes in northern temporal Europe. Furthermore, the occurrence and frequency of fires are related to the landcover type and a correlation between these fire pixels, human infrastructure and spatial policy has been observed.

The results have shown that most fires occur in late winter and early spring and it fades out towards in the late summer, for the exception of forest fires, which peaks in the late summer. Heath fires are affected by high pressure zones in the later winter and early spring. However, these fires are likely related to anthropogenic activities. Most of these fire are close to infrastructure, which also conforms earlier observations in earlier research [8,33] that dense infrastructure and human activity are related to the frequency of natural fires and increase the risk of fire.

Besides the infrastructure, policy has impacted in the spatial distribution of fires (figure 5). Most fire pixels were observed in designated natural areas, such in Natura 2000 and national parks. Therefore, it is important to gain further insight into how recreational behaviour of human in natural areas are affecting the risk of fire on a regional level

The seasonal pattern can be related to the high-pressure zone in central western Europe in spring and decrease precipitation in the winter [38]. This causes a decrease in soil moisture content and increase in plant transpiration. This increase the risk of fire which results in a peak in early spring.

With these finding, risk management can focus on the implementation of fire policy surrounding designated areas and increase in risk in early spring. Furthermore, it can possible pinpoint risk areas, so infrastructure and human health risks is averted.

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