# Introduction

Wildfires are vital for various ecosystem, such as savannahs and boreal forests. They have taken a critical role in development and sustainability for these ecosystems. While the main cause of natural ignition has been lighting [1], for over the last millennium, fires are increasingly used and/or are indirectly ignited by humans. At first, the purposes of these fires were to modify specific areas, so human could prepare these regions for agricultural activity, domestic purposes, or were used as war strategies. These purposes have changed drastically for the last 300 years. Fires are being suppressed in modern civilization, so agricultural or industry rich areas are protected against the consequences of these fires, or they are used to acquire and expand farmland. The prevention measurements cause accumulation of fuel in fire sensitive climates, which could result in intense wildfires. Otherwise, the expansion and making of agricultural land are reducing area for fire vital ecological systems and reduces the amount [2]. The change in fire management and measurements has resulted in a decline in the amount of global burned area over the last 18 years [3].

While a reduction of burned area has been observed, the rise of the mean global temperature and the forthcoming climatological effects have increased and is increasing the risk of the fires over the last century. These effects are changing the fire seasons and fire regimes in various regional climates. The increase of temperature is caused by several greenhouse gases, such as methane and carbon dioxide, which are emitted by fossil fuelled human activity. The effects of these greenhouse gasses is observed in various atmospheric and biochemical cycles [4]. It can introduce fire regimes and fire seasons into currently low risk fire 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. The climatological effects could be amplified by the changes in the local landcover as a response to the warmer and drier climate [6].

These changes 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 are going to effect the local population for a short and/or long period of time [9,10]. It results sometimes in rioting, habitat loss for wildlife and the severe damage on structures and properties in the region [7,11].

In Europe, around 70% of the fires and 85% of the burned surface area are currently in the Mediterranean Region. While wildfires and the consequences have been extensively researched in the Mediterranean area [8,12,13], global change does not only effect Southern Europe. The risk of fire is predicted to increase in currently wetter climates in Western Europe. 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 an European country where fire is predominantly present.

The Netherlands is one of the effected countries in Western Europe, whereby an increasing risk of forest fires is predicted if the rise in temperature is going to continue over the 21th century [14]. The country has several unique spatial and population characteristics that could greatly impact how wildfires start and give insight into how policy and population are influence future wildfires. The spatial policy of this country has a rich history in spatial planning and in general water management. This lead in the 20th century to greatly improving the Dutch waterworks to protect cities and the various spatial policies to stimulate economic growth. These developments resulted in a highly fragmented landscape and high dense highway infrastructure [15][16,17]. Another characteristic of the Netherlands is that it has the highest population density per square kilometre in Europe with 513 people / km2 ‑[15]. This could be related how population influences the fire regime in high density areas.

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

These characteristics can be highly effecting the current and future fire regimes of the Netherlands, because most forest fires are indirectly caused by human agents [8]. Furthermore, the chance of fire is higher, when the natural is closer to human infrastructure [12]. Therefore, NATURA 2000 areas are interesting to observe, because fires can be doing the most 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.

Our 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*

As stated in the introduction, the Netherlands is the research area of the study. The spatial data about the country is downloaded from a service, named the Public Services on the Map (NL: Publieke Dienstverlening op de Kaart; PDOK). It is an open data platform where people find various governmental related spatial datasets 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; NWP). 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*

Active fires around the world are observed deducted from various satellite sources. One of these satellites is the Suomi National Polar-orbiting Partnership (S-NPP), which has the Visible Infrared Imaging Radiometer Suit (VIIRS).

The satellite orbits around the earth at an altitude of 829 km and crosses the twice equator when ascending around 13:30 (Greenwich time) and 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 [21].

An algorithm by Schroeder et al.(2014) has been developed to find active fire information from the VIIRS raster data. The input for this algorithm is the data from the I4 sensor of VIIRS. This sensor measures the mediumwave infrared (MIR) spectrum between 3.55 - 3.93 µm. The specific colour temperature of the electromagnetic radiation indicates if there is or is not active. The other sensors from the I-bands are used for verification of the active fire and the data quality. With the help of the DNB, it measures active fires at day and night. This data is acquired for each month and saved in an ASCII file with the file name VNP14MLIMG. The aggregation scheme keeps therefore 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 the various land cover types, the different sizes and time span of the observed fires. It detects smaller (lower than 100 ha) fires and is improved on the detection of boreal fires and savannah fires, while the algorithm has a lower performance against agricultural fires. Overall, the dataset is suited for the detection of natural active fires [23].And is used to get information wildfires in natural areas in the Netherlands.

These datasets are downloaded from [*ftp://fuoco.geog.umd.edu/VIIRS/VNP14IMGML*](ftp://fuoco.geog.umd.edu/VIIRS/VNP14IMGML) *(last accessed in May 2020)*. The data cover a period from 01-2012 to 05-2020.

*2.1.3 Land cover datasets*

Land cover data are the Corine Land Cover (CLC). The dataset is the result of satellite date of the SENTINEL 2 and Landsat-8. The SENTINEL-2 is part European earth observation program that is used for acquiring high resolution data of the land surface and identifying natural hazards [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 CLC 2018 dataset has been developed between 2017 to 2018 and the CLC 2012 dataset between 2011-2012. 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 datasets from 2012 and 2018 are used and are downloaded from [https://land.copernicus.eu/pan-euro pean/corine-land-cover/clc2018?tab=download](https://land.copernicus.eu/pan-euro%20pean/corine-land-cover/clc2018?tab=download) (last accessed in May 2020) and <https://land.copernicus.eu/pan-european/corine-land-cover/clc-2012?tab=download> (last accessed in September 2020). It is open access.

*2.1.4 Natura 2000 and National parks*

The European Union (EU) set up a program to protect endangered species to ensure, sustain and increase European biodiversity. The network with these sites has been set out over the EU with the help of the Birds- and Habitats-directive and is called Natura 2000.

162 areas in the Netherlands that part of the Natura 2000 network. 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 by the wildfires caused by climate change. 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 scripts that are developed for parsing and analysing the VIIRS, CLC, and PDOK files can be found on <https://github.com/CUniversityaccount/ForestFireNetherlands>.

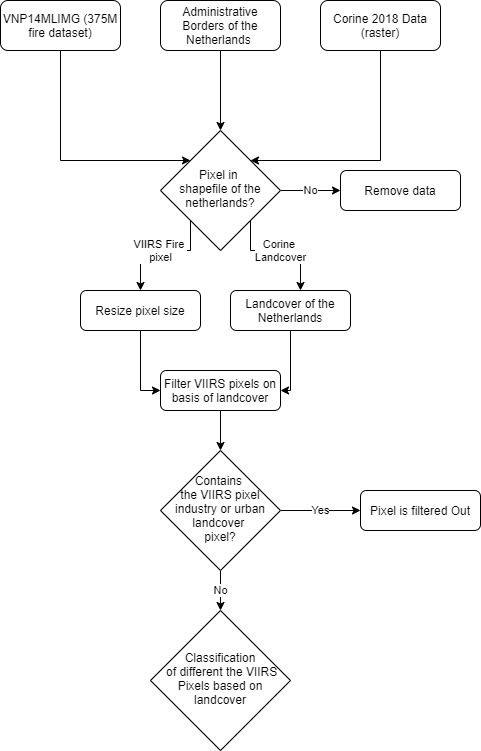


Figure 1 Flowchart on how the fire pixels derived from the active fire algorithm are filtered and classified based on CLC pixels

The general overview of the method for acquiring the data can be seen in figure 1.

*2.2.1 Filtering of the VIIRS Fire pixels based on location*

The data from the VIIRS dataset is filtered based on the location of the centre of the pixel. If the pixel is not in the administrative borders of the Netherlands than the pixel is filtered out.

After the non-relevant pixels are filtered out, the size of the pixel is determined. This is done with the horizontal position of the pixel in the dataset, whereby the starting point of the observations is the nadir.

The change in angle, observation distance and curvature of the earth causes the increasing size of the from the centre of the measurements. VIIRS compensates the factors with the help of multiple bands and aggregation scheme. This keeps most the pixel sizes 375 meter up to the 960th observation .After this observation, the aggregations scheme and sensors only can compensate the pixel size up to 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.

*2.2.2 Filter and classification of the fire pixels*

The fire type classification of the pixels has two objectives. It filters out the pixels which are not classified or has any natural land covers and the CLC data is used for the classification of the fire type of the fire pixel. The used landcover dataset is the CLC dataset. The 2012 CLC dataset is developed between 2011 – 2012 and the 2018 CLC-dataset is developed in 2017-2018. The 2012 CLC dataset is used until 2016 and the 2018 dataset from 2016. This is to keep the land cover as accurate as possible. These datasets has a three levels hierarchy. These are levels are defined with three number code (head-class, sub-class, specific landcover number) [28].

A pixel is filtered if there is/are:

* A single industrial or urban pixel, because the exact origin of the fire, could be a mechanical or urban object (CLC pixels between 0 and 200).
* All landcover pixels in the fire pixel are from the waterbody headclass (values between 500 and 600).
* 50% or more of the CLC pixels are from agricultural origin, because these fire pixels could be identified because of greenhouses and human agricultural activity.

The output is classified by the most dominant natural CLC-type for the exception of combined nature because the origin of this fire pixel could not be exactly based on the classification in the table be determined. The names and the CLC value ranges to be classified can be seen in table 1:

|  |  |
| --- | --- |
| 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 filtered 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.

*2.2.4 Fires in natural designation areas*

The quantification of pixels based on location is done with the Nature 2000 areas and natural parks. All 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

Results

Line chart

Description automatically generated

Figure 2 The amount of fire pixels per year with a linear regression line. The light grey line are the observed values, and the black line is the linear regression line. The χ2 value that result from the linear regression is 3.7%.

The number of fire pixels of the identified active fire pixels were filtered down to n = 138. Linear regression was applied to verify if the amount of fire pixels is increasing or decreasing in the studied years (see figure 2). It resulted that it seems that the number of fire pixels is increasing. However, the χ2-statistic illustrated that there was a low correlation between the observed and the expected fire pixels. Therefore, it cannot be stated that the amount of fire pixels is not increasing nor decreasing for the last decade.

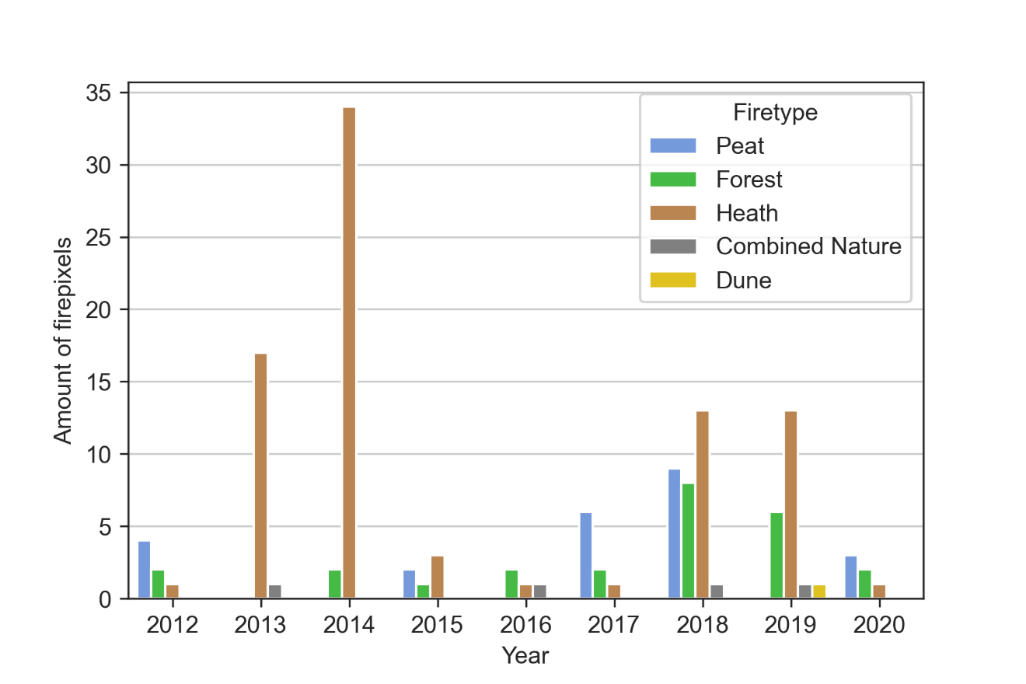


Figure 3 Yearly amount of fire pixels for each fire type.

When looking closer at the different fire types, the same observation is between the different fire pixels over the years. There is no clear trend of increasing or decreasing number of pixels over the last decade for the different fire types (Figure 43). The only remarkable observation is that there is a single dune pixel. The absence of the dune fires could be related to the definition of CLC and the definition of the general population, which is more a sematic problem than an observational problem.

Chart, box and whisker chart

Description automatically generated

Figure 4 Visualization of the type fire pixel per month for each year.

For the months, October, November and December, there were no fire pixels observed or detected. The heath fire pixels are observed between the mid-winter until late spring and in different months for each year. The mentioned time frame by the heath fire pixels is the same for the peat fire pixels. Forest does not occur as much in comparison against heath fires for the exception of 2018 and occurred on a smaller scale compared to peat and heath fires. Most forest fire pixels are observed within last 3 years.

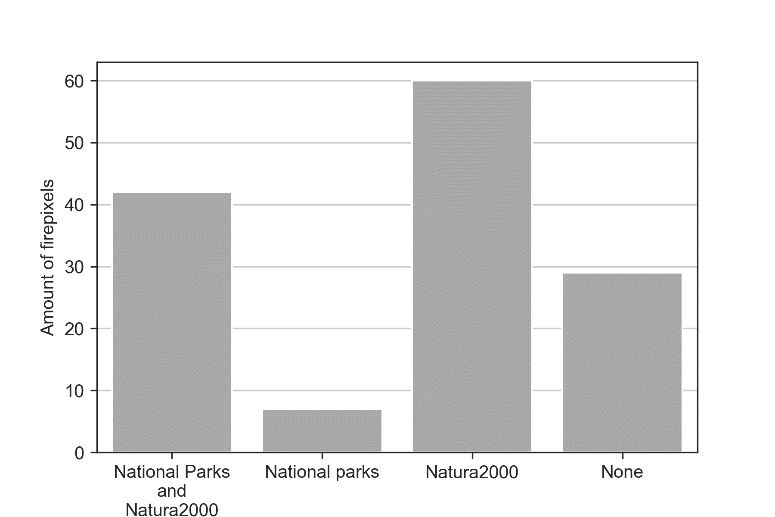


Figure 5 The amount of fire pixels (n=138) which are measured in National Parks and/or Natura 2000 areas

For around 79% of the fire pixels occurred are within Natura 2000 or within the national parks (see figure 6). The observation demonstrates that the fire pixels in natural landcover types and designated areas are related to the stated spatial policies on a regional level. It also illustrates that these natural areas have a higher risk of fire in comparison of the non-designated natural areas. These occurrences of fire could be related to the accumulated amount of fuel in the land and type of landcover.

Chart, histogram

Description automatically generated

Figure 6 Histogram which shows the relative distance between a fire pixel and the Dutch infrastructure

Another spatial characteristic of the fire pixels is that most fires pixel occurred within 500 meters of a road. Considering that most fire are occurring in important and stated protected natural borders and national parks, concludes that human activity within these areas has an impact on the natural state. Therefore, the activity of humans (figure 4) relates to the frequency and location of occurrence of fires pixels. It could explain why there cannot be a cycle could be observed (figure 3).

Discussion

*Limitations and uncertainties of observed fire pixels*

The various limitations of the data are partly influencing the results. Oliva and Schroeder (2015) demonstrated that the identification of fires in grassland and heath have a higher commission error in comparison with other land cover types. Most of the identified fire pixels are heath, which could lead of some false positives and none observed fire pixels.

Some wildfires are also not identified, because of the frequency which the satellite a location observes on a day. The VIIRS instrument has a 12 hour gap between each observation on a specific location [29], which could miss fires, which were only active in the 12 hour gap. The data is therefore not complete.

Another limitation of the data is that the location of the fire cannot precisely be determined. VIIRS observes small fires up to the size of 25% of a LANDSAT-8 pixel (with 30 meter) [22,23], but the exact size and location of the wildfire cannot be deducted with only data of the VIIRS pixel. The combined nature fire pixels cannot be clearly distinguished which type of fire pixel is. These pixels are therefore not included in the seasonal effects foreach fire type. This implicates that some information is missing about the seasonal effects on the 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 the observed fires. These characteristics is important to get information about the local spatial pattern of the fire, the cause and timeframe of the fire and potentially the impact on the local population and infrastructure, which are used in risk management.

Some fires are small or are active over a small period of time, while other fires could stretch over several days and a larger area. Therefore, the amount of detected fire pixels is an indication that one that location a fire has been observed but the pixel could be part of a fire which burns an area bigger than the observed pixel.

*Location of the fires*

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 **X**, the **PERCENTAGE** of the pixels are in 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]. It could be related that there are more fires in the Natura 2000 areas than the Dutch natural parks.

*Abiotic and biotic effects on the fire regime*

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. 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 Netherlands [33], which increase the risks of natural fires in spring. The phenomenon could show why there are no forest fires in the autumn, while there are fire pixels in the winter.

*Human influences*

While abiotic and biotic factors are impacting the risk of fires, the key to finding the driving force of the Dutch fire regime is the mapping and analysing human activity in the protected areas. As Pechony and Shindell [32] and Ganteaume *et al.*[8] have correlated that the higher population density effects and increases the occurrences of wildfires and observed that fire ignition and fire suppression is increasing with a higher population density. The results do not indicate that there is a reoccurring seasonal timeframe whereby the fire pixels are observed, has not been observed in the current climate in the Netherlands. However, the low distance between a fire pixel and a road indicates that these observations and relations are relevant for 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 its surrounding [12]. While the Netherlands has a climate with a milder temperature and higher amount precipitation [36], these observations can be applied to this situation, because the country has one of the highest population densities in Europe [37], has high density infrastructure [15] and most of the observed fire pixels are in a radius of less than 500 meter.

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