**CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE**

**FACULTY OF ENVIRONMENTAL SCIENCES**

DEPARTMENT OF SPATIAL SCIENCES

# REMOTE SENSING OF NIGHT POLLUTION IN NATIONAL PARKS OF THE CZECH REPUBLIC

BACHELOR THESIS

THESIS SUPERVISOR: ING. DAVID MORAVEC, PH.D.
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# CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Environmental Sciences

# BACHELOR THESIS ASSIGNMENT

Ostoja Cvijetić

Geographic Information Systems and Remote Sensing in Environmental Sciences

Thesis title

**Remote sensing of night light pollution in national parks of the Czech Republic**

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## Objectives of thesis

Main objective of the thesis is to investigate the overall development of night light pollution affecting the area of the Czech national parks during the last decade. Further objectives are to gain insight into the how the light pollution affects the area of interest in both bad and good ways in respect to natural cycles of flora and fauna. Also the thesis will pay attention to the technology used to monitor this phenomena, especially the satellites, past and present.

## Methodology

The Google Earth Engine will be the main tool to collect the necessary data. This will be accomplished by using the scripts specifically created in order to obtain the VIIRS night light datasets over the selected period of time. Further these data will be extracted to be statistically and visually analyzed in other tools and programs such as R, Python and ArcGIS. Results will be appropriately interpreted and presented trough tables, graphs, maps and images.

**The proposed extent of the thesis**

30 – 40 pages

**Keywords**

Remote sensing, Night light pollution, Google Earth Engine, VIIRS, National parks

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**Recommended information sources**

Chalikias, C., Petrakis, M., Psiloglou, B., Lianou, M., (2006). Modelling of light pollution in suburban areas using remotely sensed imagery and GIS. Journal of Environmental Management 79 (2006) 57–63.

Katz, Y., Levin, N. (2016). Quantifying urban light pollution — A comparison between field measurements and EROS-B imagery. Remote Sensing of Environment 177 (2016) 65-77

Levin, N., Kyba, CCM., Zhang, Q., et al. (2019). Remote sensing of night lights: A review and an outlook for the future. Remote Sensing of Environment 237 (2020) 111443.

Rajkhowa, R. (2014). Light Pollution and Impact of Light Pollution. International Journal of Science and Research (IJSR).

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**The Bachelor Thesis Supervisor**

Ing. David Moravec, Ph.D.

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Electronic approval: 3. 3. 2023

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Electronic approval: 6. 3. 2023

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Dean

Prague on 30. 03. 2023

## Declaration

I declare that I developed this bachelor's thesis independently under the supervision of Ing. David Moravec, Ph.D., and that I have listed all the literary sources and publications from which I drew.

Prague, 2023 Ostoja Cvijetić

## Acknowledgment

First of all, I would like to thank my supervisor Ing. David Moravec, Ph.D., especially for the patience and understanding, not just throughout the completion of thesis, but also throughout the whole studies. I would also like to thank all other teachers who guided me and my colleagues in the very particular circumstances, especially at the beginning of our studies. I am also grateful to my fellow student colleagues for supporting each other throughout our journey. And finally, special thanks goes to my girlfriend Elena Timofeeva, as without her support I wouldn’t be where I am now.

# Abstract

Night light pollution, or artificial light at night (ALAN), has become a significant environmental issue that affects both the natural and human world. This bachelor thesis aims to investigate the overall development of night light pollution affecting the area of the Czech national parks during the last decade (2014 - 2022). The study was conducted by collecting data from various sources , including peer-reviewed scientific journals, online databases and official reports.

The research begins with an overview of the causes and sources of night light pollution, followed by a detailed description of the various effects of ALAN on the environment.

The research also investigates the importance of remote sensing in the study, processing and analysis of night light pollution.

For collection data I used programming languages such as Java and Python. Also, for collection data I used Google Earth Engine.

In conclusion, this bachelor thesis demonstrates that night light pollution is a significant environmental problem that has a profound impact on the environment and human health. The study suggests that there is an urgent need for effective strategies to reduce the harmful effects of ALAN. The research recommends the use of responsible lighting practices, such as the use of energy-efficient lighting and shielding lights to minimize light pollution.

## Key words:

Remote sensing, Night light pollution, Google Earth Engine, VIIRS, National parks

# Abstrakt

Noční světelné znečištění neboli umělé noční osvětlení (ALAN) se stalo významným environmentálním problémem, který ovlivňuje jak svět přírody, tak i člověka. Tato bakalářská práce si klade za cíl prozkoumat celkový vývoj nočního světelného znečištění ovlivňujícího území českých národních parků v posledním desetiletí (2014 - 2022). Studie byla provedena sběrem dat z různých zdrojů, včetně recenzovaných vědeckých časopisů, online databází a oficiálních zpráv.

Výzkum začíná přehledem příčin a zdrojů nočního světelného znečištění, následuje podrobný popis různých vlivů ALANu na životní prostředí.

Výzkum také zkoumá význam dálkového průzkumu Země při studiu, zpracování a analýze nočního světelného znečištění.

Pro sběr dat jsem použil programovací jazyky jako Java a Python. Pro sběr dat jsem také použil Google Earth Engine.

Na závěr tato bakalářská práce ukazuje, že noční světelné znečištění je významným environmentálním problémem, který má zásadní dopad na životní prostředí a lidské zdraví. Studie naznačuje, že existuje naléhavá potřeba účinných strategií ke snížení škodlivých účinků ALAN. Výzkum doporučuje použití odpovědných osvětlovacích postupů, jako je použití energeticky účinného osvětlení a stínicích světel, aby se minimalizovalo světelné znečištění.

## Klíčová slova:

dálkový průzkum Země, Noční světelné znečištění, Google Earth Engine, VIIRS, Národní parky

# Overview of used abbreviations

| | |
|---|---|
| ALAN | Artificial light at night |
| a.s.l. | Above sea level |
| CSV | Coma separated value |
| DMSP | Defense Meteorological Satellite Program |
| GEE | Google Earth Engine |
| GIS | Geographic information system |
| JPSS | Joint Polar Satellite Systems |
| LiDAR | Light Detection and Ranging |
| NP | National Park |
| OLS | Operational Linescan System |
| RS | Remote Sensing |
| Suomi NPP | Suomi National Polar-orbiting Partnership |
| VIIRS | Visible Infrared Imaging Radiometer Suite |

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# 1. INTRODUCTION

Even though amongst large number of types of pollution we impose on our environment, due to its peculiar nature, light pollution is not the first thing that comes to mind of most of the people, it is still a growing environmental concern with a strong impact on human health, wildlife, and our ability to look at the night sky, either to enjoy its beaty or for scientific purposes. As national parks are intended to protect and preserve natural habitats and natural behavior, we are obliged to pay special attention to them when it comes to any type of pollution, which also includes light pollution as they can prove to be especially vulnerable to its effects.

To better understand the extent and impact of light pollution in national parks, this study analyzed Visible Infrared Imaging Radiometer Suite (VIIRS) night light data for both whole Czech Republic and its national parks. VIIRS was used as it is an instrument which is able to capture high-resolution images of earth at night, which allowed better assessment of light pollution levels.

# 2. GOALS

Main goals of this study are to identify how the night light pollution developed over time in the area of national parks, examine which factors possibly contributed to this kind of development and try to understand how it can potentially affect the natural habitats. Study also tries to identify if there are some areas which should be monitored especially due to higher rate of light pollution.

The findings of this study could possibly be used to improve further efforts to reduce night light pollution in national parks.

# 3. LITERATURE REVIEW

## 3.1. Night Light Pollution

Night light pollution, also known as artificial light at night (ALAN), is the excessive or unnecessary use of artificial light during the night that interferes with the natural darkness and rhythms of the night environment (Gaston K. J., Reducing the ecological consequences of night-time light pollutin: options and developments, 2013).

The sources of artificial light at night include streetlights, buildings, billboards, sports fields, and industrial facilities (Hölker, 2010).

### 3.1.1. Sources of Night Light Pollution

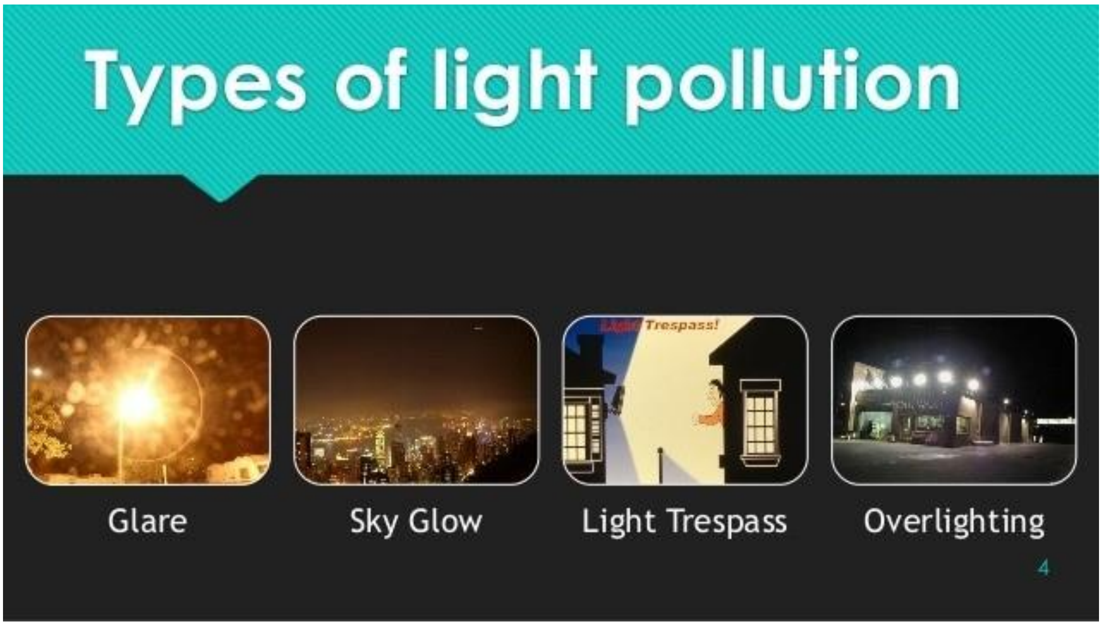
There are several types of light pollution, each with its own specific characteristics and impacts. The main types of light pollution include:

1. Skyglow – the brightening of the night sky over populated areas, caused by the scattering of artificial light by the atmosphere. This makes it difficult to observe the stars and other celestial objects (Falchi F. C., 2016).

2. Glare – the excessive brightness or contrast between light and dark areas, caused by unshielded or poorly aimed lights. This can cause discomfort and reduce visibility, especially for drivers (Boyce, 2012).

3. Light trespass - the unwanted or intrusive illumination of an area, caused by light spilling over property boundaries or from poorly aimed lights. This can cause disruption to wildlife and residents (Gaston K. J., Reducing the environmental impact of outdoor lighting, 2012).

4. Over-illumination – the use of excessive or unnecessary lighting, causing a waste of energy and resources. This can also cause glare and light trespass (Kyba C. C., 2014).


Types of light pollution

Glare

Sky Glow

Light Trespass

Overlighting

Figure 1. Examples of types of light pollution (Biondi, 2023)

### 3.1.2. Side Effects of Night Light Pollution

The phenomenon of night light pollution has been recognized as a significant environmental problem that affects both humans and wildlife. It produces a wide spectrum of side effects, which are mostly negative, but still some positive exist. Night light pollution can have several negative effects on human health. Exposure to artificial light at night can disrupt the natural circadian rhythm of the organism, which can cause sleep disturbances and associated health problems. Here are some of the key side effects of night light pollution on human health:

1. Sleep disturbance – exposure to artificial light at night can disrupt the production of melatonin, a hormone that regulates sleep, leading to difficulty falling asleep and poor sleep quality. This can have a range of negative health consequences, including an increased risk of depression, anxiety, and obesity (Obayashi K. S., 2018).

2. Cardiovascular disease – studies have linked exposure to artificial light at night with an increased risk of cardiovascular disease, including hypertension and heart disease (Obayashi K. S., 2018). This may be because exposure to

light at night disrupts the body's natural circadian rhythm and alters the production of hormones that regulate blood pressure and heart rate.

3. Cancer – there is also evidence to suggest that exposure to artificial light at night may lead to development of cancer, particularly breast cancer (Obayashi K. S., 2018). This is because exposure to light at night can disrupt the body's natural production of melatonin, which has been shown to have anti-cancer properties.

4. Mental health – Exposure to artificial light at night could also cause effects on mental health, such as increased risk of depression, anxiety, and other mood disorders (Obayashi K. S., 2018)

Night light pollution can have a range of negative effects on wildlife, particularly on species that are adopted to natural darkness. Here are some of the key side effects of night light pollution on wildlife:

1. Disruption on behavior – artificial light at night can disrupt the natural behavior of many nocturnal animals, including their feeding, foraging, and breeding behaviors (Stone, 2015). This can have a range of negative consequences, including reduced reproductive success, lower survival rates, and changes in the distribution and abundance of species.

2. Disorientation and navigation – night light pollution can also disorient animals and affect their navigation abilities, particularly for species that rely on the stars or the moon to navigate (Gaston K. J., 2013). For example, sea turtle hatchlings can become disoriented by bright lights on shore, leading them away from the ocean and reducing their chances survival.

3. Interference with communication – light pollution can also interfere with the ability of some animals to communicate with each other, particularly for species that use bioluminescent displays or light signals for mating or territory defense (Longcore, 2004).

4. Alteration of habitat – artificial light can also alter the structure and composition of habitats, particularly for species that are sensitive to light or that have specific light requirements breeding, foraging, or other activities (Gaston K. J., 2013).

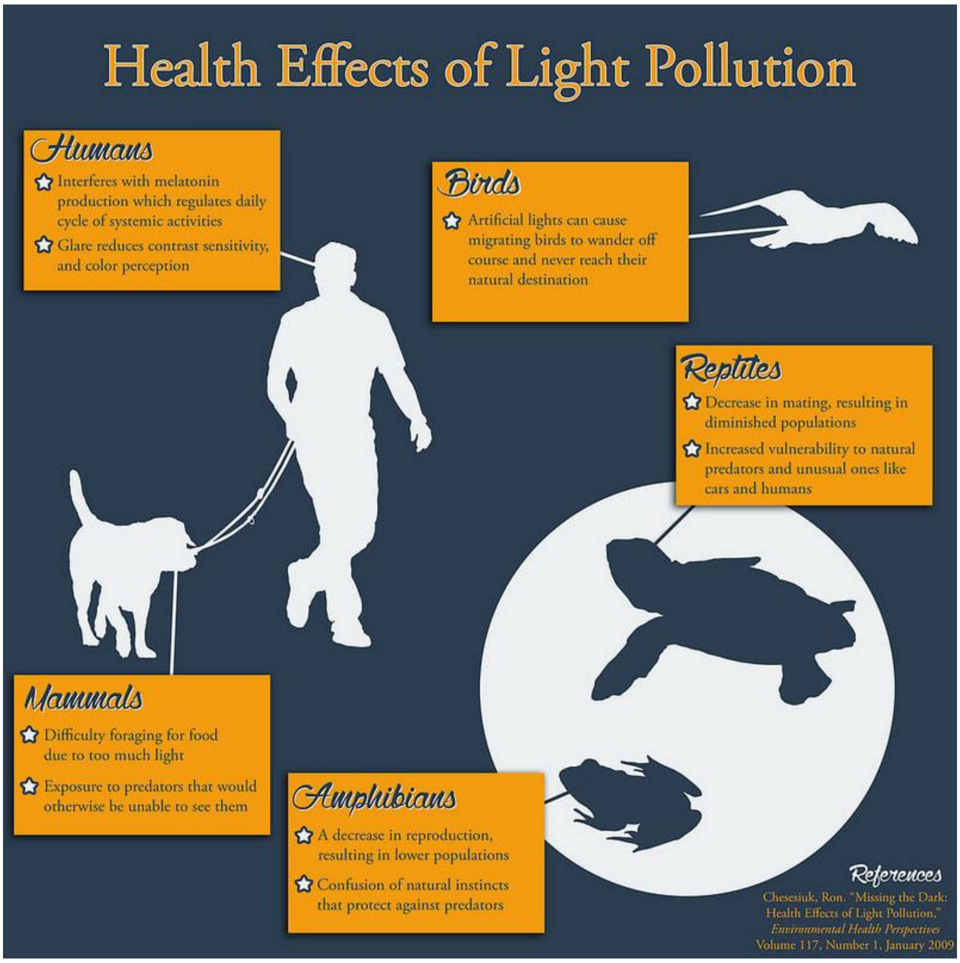
While we can see that there are a lot of negative side effects of night light pollution on human health and wildlife, there are also some potential positive effects of artificial light at night. Here are some of examples:

1. Increased safety and security – outdoor lighting can improve safety and security by reducing the risk of accidents and crime in public areas (Falchi F. C., 2016). Properly designed and placed lighting can also help prevent accidents and injuries by illuminating hazards and obstacles.

2. Support of nocturnal activities – in some cases, outdoor lighting can support nocturnal activities such as sports, recreation, and tourism, by extending the hours of operation for these activities (Falchi F. C., 2016). For example, well-lit parks and public spaces can allow for safe and enjoyable nighttime activities.

3. Promotion of urbanization – outdoor lighting can also promote urbanization by increasing the perceived safety and attractiveness of urban areas, leading to increased investment and development (Gaston K. J., 2013).

However, it is important to note that these potential positive effects of night light pollution should be balanced against its negative effects on human health and wildlife. Minimizing unnecessary or excessive use of outdoor lighting and using appropriate lighting design and technology can help mitigate the negative effects of light pollution while still providing the benefits of artificial light at night.



Health Effects of Light Pollution

Humans

- Interferes with melatonin production which regulates daily cycle of systemic activities
- Glare reduces contrast sensitivity, and color perception

Birds

- Artificial lights can cause migrating birds to wander off course and never reach their natural destination

Reptiles

- Decrease in mating, resulting in diminished populations
- Increased vulnerability to natural predators and unusual ones like cars and humans

Mammals

- Difficulty foraging for food due to too much light
- Exposure to predators that would otherwise be unable to see them

Amphibians

- A decrease in reproduction, resulting in lower populations
- Confusion of natural instincts that protect against predators

References

Chesesiuk, Ron. "Missing the Dark: Health Effects of Light Pollution," *Environmental Health Perspectives* Volume 117, Number 1, January 2009

Figure 2. Effect of light pollution on human health and animals (Light Pollution Effects, n.d.)

## 3.2. Remote Sensing of Night Light Pollution

Remote sensing of night light pollution refers to use of satellite data to measure and map the amount and intensity of artificial light at night in urban areas (Kocifaj, 2015). This technique involves capturing the visible and infrared light emitted from artificial light sources and analyzing the data to produce maps of the distribution and intensity of light pollution. Remote sensing techniques have been used to monitor the growth of light pollution over time and to investigate its environmental and health impacts (Falchi F. C., 2016).

Remote sensing of night light pollution is not only limited to urban areas but can also be used to study the effects of light pollution on protected areas such as natural parks. For instance, researchers have used satellite data to study the extent and effects of light pollution on protected areas in the United States, such as national parks and wilderness areas (Elvidge C. D., 2010). The data collected through remote sensing techniques can help to identify areas of high light pollution and assess its potential impacts on wildlife and ecosystems in protected areas.

Additionally, remote sensing of night light pollution can provide more applicable possibilities such as: energy management, public health, security, economic development etc.

### 3.2.1. Types of Remote Sensing of Night Light Pollution

There are several techniques used for remote sensing of night light pollution. These techniques differ in terms of the type of data collected, the sensors used, and the analytical methods employed. Here are some of the common techniques used:

1. Satellite-based remote sensing – satellite-based sensors such as the Defense Meteorological Satellite Program's Operational Linescan System (DMSP/OLS) and the Visible Infrared Imaging Radiometer Suite (VIIRS) collect data on the Earth's surface at night. These data can be used to produce maps of artificial light sources and to monitor changes in light pollution over time (Kyba C. C., 2017).

2. Ground-based remote sensing – ground-based sensors such as sky-quality meters and all-sky cameras are used to measure the brightness of the night sky at various locations. These data can be used to identify areas with high levels of light pollution and to monitor changes in sky brightness over time (Aubé, 2010).

3. Airborne remote sensing – Airborne sensors such as LiDAR (Light Detection and Ranging) and hyperspectral cameras can be used to collect high-resolution data on the intensity and distribution of artificial light sources. These data can be used to identify specific sources of light pollution and to study the effects of light pollution on ecosystems and wildlife (Cinzano, 2015).

4. Citizen science – citizen science program such as Globe at Night and the Darks Sky Meter app allow individuals to collect data on sky brightness and submit their observations to a centralized database. These data can be used to study the spatial and temporal patterns of light pollution and to identify areas where light pollution is particularly severe (Kyba C. C., 2015).

### 3.2.2. Overview of Satellite-based Remote Sensing of Night Light Pollution

As this work relies heavily on satellite-based remote sensing, there is need to put more emphasize on this topic, which will be provided in this part of the text.

Satellite programs that focus on night lights have been around since 1970s when the Defense Meteorological Satellite Program (DMSP) began collecting data on the Earth’s surface at night using a low-light imaging sensor called the Operational Linescan System (OLS) (Elvidge, C. D., & Chen, Z., 1997). The OLS sensor was primarily designed to detect and track clouds at night but also provided a measure of the intensity of artificial light sources on the Earth’s surface. The OLS data has been used to produce global maps of night lights and to study the spatial and temporal patterns of light pollution over time (Elvidge C. D., 2001).

In 2011, the Visible Infrared Imaging Radiometer Suite (VIIRS) instrument was launched as part of the National Oceanic and Atmospheric Administration’s (NOAA) Joint Polar Satellite Systems (JPSS). The VIIRS instrument is capable of capturing high-resolution images of the Earth’s surface at night, allowing researchers to study the distribution and intensity of artificial light sources with greater accuracy and detail than was possible with previous satellite sensors (Kyba C. C., 2014).

Other satellite programs that have been used to study night lights include the European Space Agency’s Sentinel-3 satellite and the Suomi National Polar-orbiting Partnership (NPP) satellite, which carries the VIIRS instrument. These satellite programs have contributed to our understanding of the effects of light pollution on the environment and human health, as well as the economic costs of wasted energy associated with excessive artificial lighting (Falchi F. C., 2016).

## 3.3. Processing and Analyzing of Night Light Pollution Data Overview

There exist various techniques in multiple programs and tools for analyzing and processing, or even obtaining night light pollution data. This chapter will provide a brief overview of some of the most common software programs, which will also be used for conducting this research, while underlying their night light analyzing properties. Those are:

1. Google Earth Engine (GEE) – a cloud-based program for analyzing geospatial data, including night light data. GEE provides a variety of tools for processing and analyzing large datasets, such as filtering, masking, and reprojecting images, as well as computing indices and statistics. GEE also allows for the use of machine learning algorithms for classification and prediction. Some examples of night light analysis in GEE include the use of time-series analysis to detect changes in night light pollution over time (Chen, 2020), and the use of clustering algorithms to identify patterns of urbanization and light pollution (Wang, 2021).

2. ArcMap – a desktop GIS software program that can be used for processing and analyzing night light data. ArcMap provides tools for georeferencing, reprojecting, and resampling images, as well as tools for computing indices and statistics. ArcMap also allows for the use of raster and vector analysis in ArcMap include the use of hotspot analysis to identify areas of high and low light pollution (Liu, 2017), and the use of regression analysis to model the relationship between night light pollution and socioeconomic factors (Li, 2019).

3. R – a programming language and software environment for statistical computing and graphics. R can be used for processing and analyzing night light data, particularly in combination with geospatial packages such as raster and sf. R provides tools for filtering, masking, and resampling images, as well as tools for computing indices and statistics. R also allows for the use of statistical models and machine learning algorithms for classification and

prediction. Some examples of night light analysis in R include the use of time-series analysis to detect changes in night light pollution over time (Kyba C. C., 2017), and the use of regression analysis to model the relationship between night light pollution and ecological factors (Gaston K. J., 2018).

### 3.4. Challenges and Opportunities for Future Research

The field of remote sensing of night light pollution offers both challenges and opportunities for future research. One challenge is the need for improved data quality and consistency across different sensors and platforms. This requires developing better calibration and correction methods, as well as more standardized data processing protocols (Zhang, Q., & Ban, Y., 2019). Another challenge is the need to better understand the underlying factors driving patterns of light pollution, such as urbanization, transportation infrastructure, and energy use, and how these factors interact with ecological and environmental processes (Gaston K. J., 2013).

However, there are also many opportunities for advancing our understanding of night light pollution through remote sensing. One promising way may be the development of more advanced algorithms used for processing and analyzing night light data, such can be machine and deep learning techniques. These approaches can enable more accurate and efficient classification of different sources of light pollution and better identification of spatial and temporal patterns (Wang, H., Zhang, Y., & Cao, C., 2021). Another opportunity is the integration of night light data with other remote sensing data, such as land cover, climate, and vegetation indices, to better understand the complex interactions between light pollution and environmental processes.

Overall, the challenges and opportunities in the field of remote sensing of night light pollution highlight the need for continued research and cooperation between scientists, governments, and other interested parts to address this important environmental issue.

# 4. CHARACTERISTIC OF THE STUDY AREA

## 4.1. Bohemian Forest (Šumava) national park

Bohemian Forest (Šumava) national park has been established in 1963, and it spreads over area of approximately 690 square kilometers, which means that it is the largest national park in Czech Republic. It is situated along the Czech-German border in the southwestern part of Czech Republic (Territory Administered by the Šumava NP, n.d.).

Bohemian Forest represents one of the oldest mountain ranges in Central Europe. While it rises from an altitude of about 700 m a.s.l. (above sea level), the core of the range is a vast plateau of Šumava Plains with an altitude of around 1000 m a.s.l. (Natural Circumstances, n.d.).

Even though forest comprise the 80% of the territory of the national park, it still has very diverse nature which also includes peat bogs, treeless block fields, lake cirques, wetland and frost treeless areas, relict pine forests, etc. (Biotopes, n.d.). There is also a great number of important species and endangered species such as the lynx, otter, and black grouse (Important Species, n.d.).

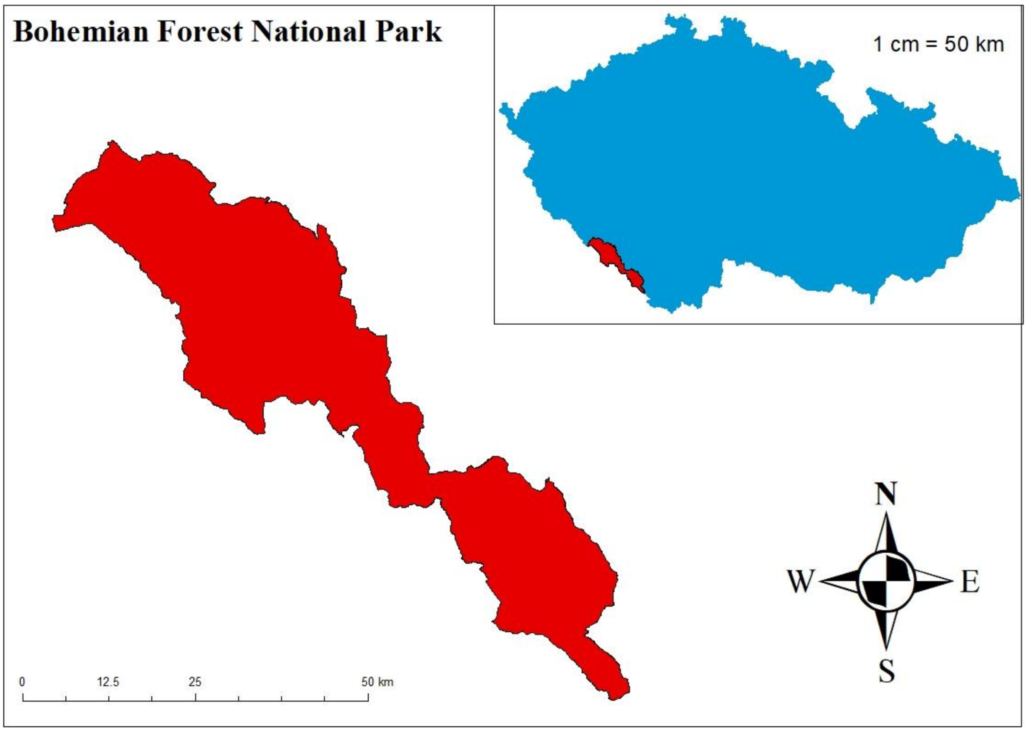


Figure 3. Bohemian Forest National Park map

### 4.2. Bohemian Switzerland (České Švýcarsko) national park

Bohemian Switzerland (České Švýcarsko) national park was established in year 2000, which means it is the youngest national park in Czech Republic. It is situated at the northern border of Czech Republic towards Germany, and it's connected with Saxon Switzerland national park which is in that country. The area which park covers is around 80 square kilometers (The Bohemian Switzerland National Park, n.d.).

The main point of protection of this area are sandstone rock formations, where also occur rare plant and animal species. National park is also recognized by European Union, as it is included in the list of European conservation areas – Natura 2000 (The Bohemian Switzerland National Park, n.d.)

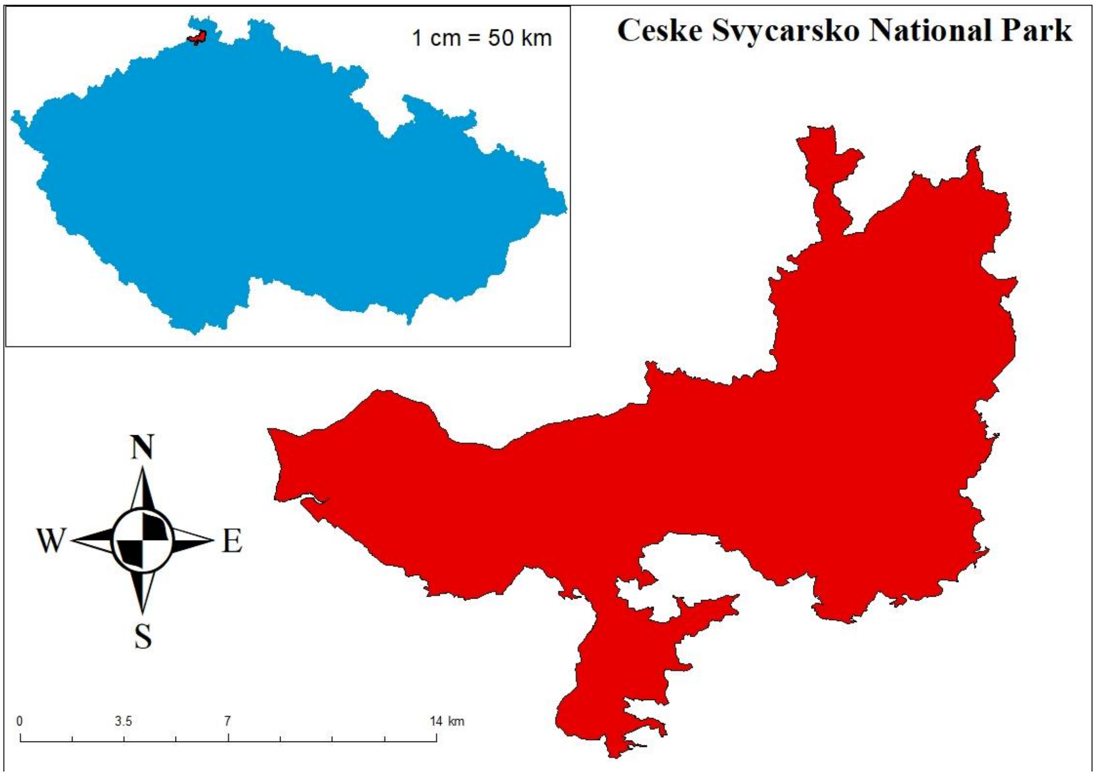


Figure 4. Map of České Švýcarsko National Park

## 4.3. Podyjí national park

Podyjí national park spreads over area of 63 square kilometers. It is located in south-eastern part of the country at the Austrian border, and is situated around the stream of Dyje. It was declared as national park in the year of 1991 (Priroda a Pece o Uzemi, n.d.).

The Dyje Canyon created a special river phenomenon which meanders through deep valleys and different rock formations. It is home to around 65 species of mammals, 7 species of reptiles, important amphibians such as spotted salamander. Park is also reach in insects and fish species (Priroda a Pece o Uzemi, n.d.).

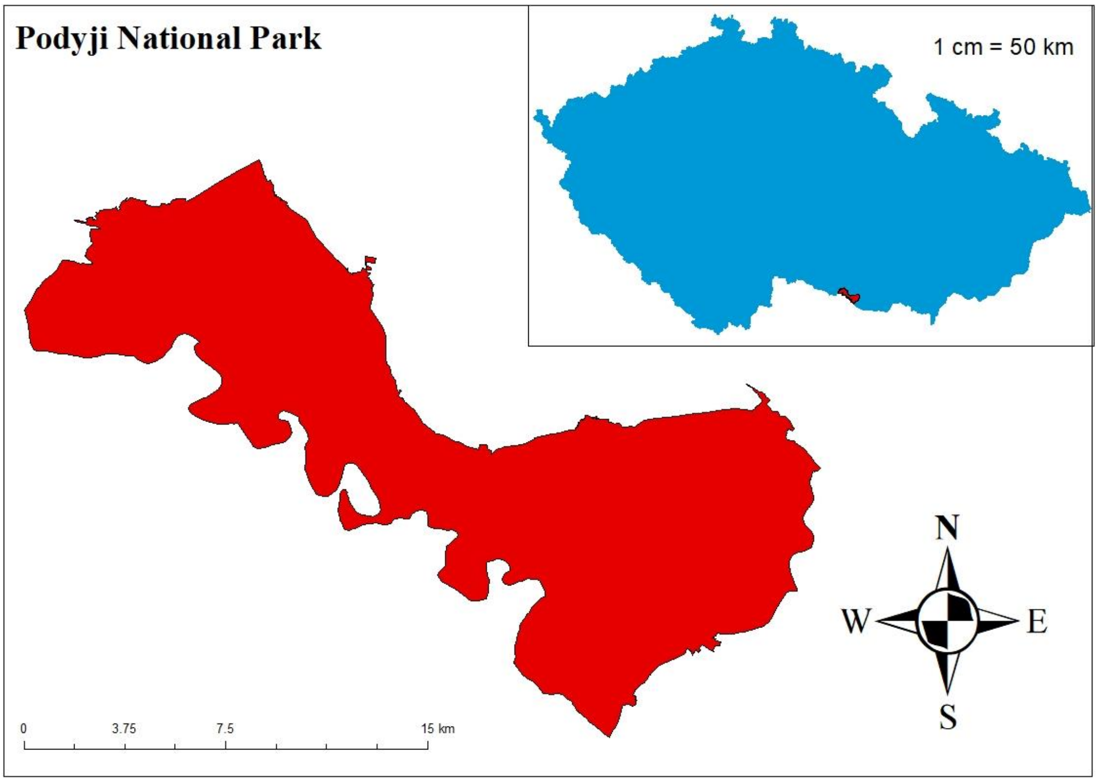


Figure 5. Map of Podyjí National Park

## 4.4. Krkonoše national park

Krkonoše national park is located on the north border of Czech Republic towards Poland. It is one of the most important centers of geobiodiversity in the country. It was declared in the year of 1963, and it covers the area of around 363 square kilometers (Vitejte v Krkonosskem narodnim parku, n.d.).

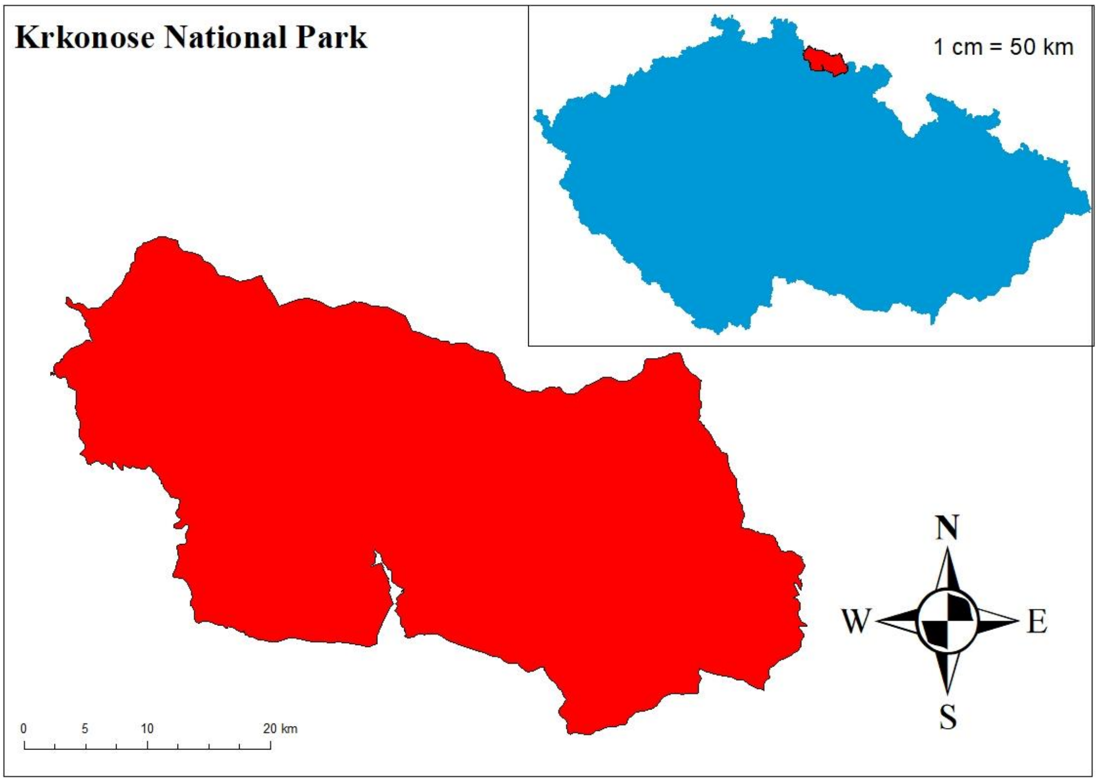


Figure 6. Map of the Krkonose National Park

# 5. Methodology

## 5.1. Collection and preprocessing

For conducting this work, I used VIIRS Stray Light Corrected Nighttime Day/Night Band Composites Version 1 data. Data was collected and preprocessed with the help of GEE. It was clipped for the Czech republic and especially its national parks from the year 2014, as that is the period from which the data is available.

Here is example of Java Script code used in GEE to obtain, visualize and export the data for the area of whole Czech Republic for the year of 2022:

```
// Load country boundary data and filter for Czechia
var Countries = ee.FeatureCollection('FAO/GAUL/2015/level0');
var country = Countries.filter(ee.Filter.eq('ADM0_CODE', 65));

// Load VIIRS data for the year 2022 and clip to Czechia
```

```
var viirs = ee.ImageCollection('NOAA/VIIRS/DNB/MONTHLY_V1/VCMSLCFG')
  .filterDate('2022-01-01', '2022-12-31')
  .select('avg_rad');
var viirs_clip = viirs.mean().clip(country);

// Define a color palette for the VIIRS map
var palette = ['black', 'blue', 'purple', 'cyan', 'green', 'yellow', 'red'];

// Create a map and add the VIIRS layer
Map.addLayer(viirs_clip, {min: 0, max: 5, palette: palette}, 'VIIRS 2022');

// Define the export parameters
var exportParams = {
  image: viirs_clip.visualize({min: 0, max: 5, palette: palette}),
  description: 'VIIRS_2022_ces',
  scale: 500,
  region: country.geometry().bounds(),
  maxPixels: 1e13,
  crs: 'EPSG:3857',
  fileFormat: 'GeoTIFF',
};

// Create an HTML legend
var legend = ui.Panel({
  style: {
    position: 'bottom-right',
    padding: '8px 15px',
    backgroundColor: 'white'
  }
});

// Create a color bar and add it to the legend
var colors = palette;
var names = ['0-10', '10-20', '20-30', '30-40', '40-50', '50-60', '>60'];
```

```
var legendTitle = ui.Label({
  value: 'VIIRS 2022',
  style: {
    fontWeight: 'bold',
    fontSize: '18px',
    margin: '0 0 4px 0',
    padding: '0'
  }
});
legend.add(legendTitle);
var colorBar = ui.Thumbnail({
  image: ee.Image.pixelLonLat().select(0),
  params: {
    bbox: [0, 0, 1, 0.1],
    dimensions: '200x20',
    format: 'png',
    min: 0,
    max: 60,
    palette: palette.join(','),
  },
  style: {padding: '1px', position: 'bottom-center'}
});
legend.add(colorBar);

// Add the legend to the map
Map.add(legend);

// Export the image and legend to Google Drive
Export.image.toDrive(exportParams);
Export.table.toDrive({
  collection: ee.FeatureCollection([ee.Feature(null, {legend: legend})]),
  description: 'VIIRS_2022_ces_Legend',
  fileFormat: 'JSON'
});
```

This same code can be modified to change the time period of interest to some other year, or even a total span between 2014 – 2022 by modifying the input in .fitlerDate command. Also, for the visualization, it may seem to be extreme to use 5 as a max value, instead of most common 60, but it was done in this example to visually emphasize the data so it can be easily interpreted with looking at the map output, especially when comparing between different periods.

Furthermore, to gain the CSV (coma separated value) file output and graphicly illustrate how the radiance values have changed throughout the selected period of time, to the original code I also added the following line of code:

```
// Reduce the VIIRS image to a single value within the country boundary
var viirs_mean = viirs_clip.reduceRegion({
  reducer: ee.Reducer.mean(),
  geometry: country,
  scale: 30,
  maxPixels: 135414886,
  bestEffort: true
});

// Print the mean radiance value for the region
print('Mean Radiance Value:', viirs_mean.get('avg_rad'));

// Create a chart of the monthly mean radiance values
var chart = ui.Chart.image.seriesByRegion({
  imageCollection: viirs,
  regions: country,
  reducer: ee.Reducer.mean(),
  band: 'avg_rad',
  scale: 30,
  seriesProperty: 'system:id'
})
.setChartType('LineChart')
.setOptions({
```

```
  title: 'Monthly Mean Radiance in Czechia (2022)',
  vAxis: {title: 'Mean Radiance'},
  hAxis: {title: 'Month'},
  lineWidth: 1,
  pointSize: 4,
  series: {
    0: {color: 'blue'}
  }
});

// Add the chart to the console
print(chart);
```

This example of the code again provides us with the output for the whole country and the year 2022, but it must be mentioned that when running this code, I changed the time period to correspond to total period between 2014-2022 so that the output will give more meaning and insight in the nature of the change.  Also, the maximum number of pixels had to be adjusted to match the number of pixels in the VIIRS data for the whole country, for this code to be able to provide desired output.

### 5.2. Data Analysis

To analyze the obtained data, I again relied on coding methods, but this time instead of Java Script I used Python. As the collection methods provided me with the csv files containing the monthly radiance values for the whole period of interest, with the corresponding date to each value I started exploring and computing some basic statistics with the following code:

```
#Imporat necessary libraries
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
from sklearn.linear_model import LinearRegression
```

```
#Load data
data = pd.read_csv('pod.csv')

#This will print the first few rows of the data
print(data.head())

#Convert the Date column to a datetime format using the to_datetime() method.
#This will allow us to work with the dates more easily
data['Date'] = pd.to_datetime(data['Date'])

#Set the Date column as the index of the DataFrame
data.set_index('Date', inplace=True)

#Plot the time series, create a line plot of the time series
import matplotlib.pyplot as plt
plt.plot(data)
plt.show()

#Compute some basic statistics, such as the mean, standard deviation, minimum, and maximum
print(data.describe())
```

As previous codes, this one is also provided with comments of each command to easier comprehend the process. This line of code was upgraded with serious of code which are necessary to provide us with the plots which give deep insight into temporal change of the data. It is as follows:

```
#Create a plot of the autocorrelation function of the time series
import statsmodels.api as sm
from statsmodels.graphics.tsaplots import plot_acf
plot_acf(data)
plt.show()
```

```
#Create a plot of the partial autocorrelation function of the time series
from statsmodels.graphics.tsaplots import plot_pacf
plot_pacf(data)
plt.show()


#Time series decomposition of the data into trend, seasonal, and residual components
from statsmodels.tsa.seasonal import seasonal_decompose

decomposition = seasonal_decompose(data)

fig, ax = plt.subplots(4, 1, figsize=(8, 8))
ax[0].plot(data)
ax[0].set_ylabel('Original')
ax[1].plot(decomposition.trend)
ax[1].set_ylabel('Trend')
ax[2].plot(decomposition.seasonal)
ax[2].set_ylabel('Seasonal')
ax[3].plot(decomposition.resid)
plt.show()


#Read in the data into Pandas dataframe
df = pd.read_csv('pod.csv')


#Convert the 'Date' column to a datetime format and set it as the index of the dataframe
df['Date'] = pd.to_datetime(df['Date'])
df = df.set_index('Date')


#Plot the data to visualize it
plt.plot(df.index, df['Radiance value'], 'o')
```

```
plt.xlabel('Date')
plt.ylabel('Radiance value')
plt.show()


#Perform a linear regression analysis on the data using scikit-learn's LinearRegression module
X = np.array(df.index).reshape(-1, 1)
y = np.array(df['Radiance value']).reshape(-1, 1)

model = LinearRegression()
model.fit(X, y)

print('Intercept:', model.intercept_)
print('Slope:', model.coef_)


#Read the data into a DataFrame
df = pd.read_csv('pod.csv')


#Split the data into two arrays
dates = pd.to_datetime(df['Date'])
radiance = df['Radiance value']


#Perform linear regression
X = dates.values.reshape(-1, 1).astype(float)
y = radiance.values.reshape(-1, 1).astype(float)
model = LinearRegression().fit(X, y)


#Plot the data and the regression line
plt.scatter(dates, radiance)
```

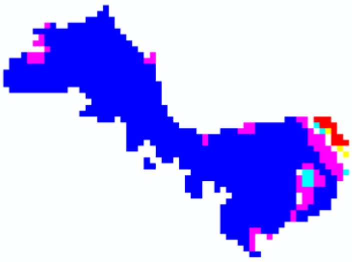
```
plt.plot(dates, model.predict(X), color='red')
plt.xlabel('Date')
plt.ylabel('Radiance value')
plt.show()



#Convert date column to datetime object
df['Date'] = pd.to_datetime(df['Date'], format='%d-%b-%y')

#Convert datetime object to ordinal representation
df['Date'] = df['Date'].apply(lambda x: x.toordinal())



#Perform polynomial regression
x = df['Date']
y = df['Radiance value']

z = np.polyfit(x, y, 3)
p = np.poly1d(z)

#Plot data and regression line
plt.scatter(x, y)
plt.plot(x, p(x), color='r')
plt.xlabel('Date')
plt.ylabel('Value')
plt.show()
```

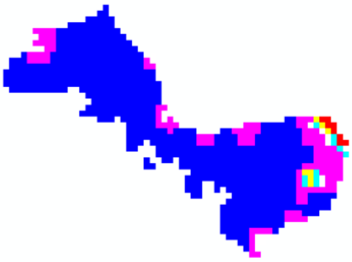
As seen from the code, it provided me with important plots such as trend, seasonal and residual components, but also the linear and polynomial regression analysis.

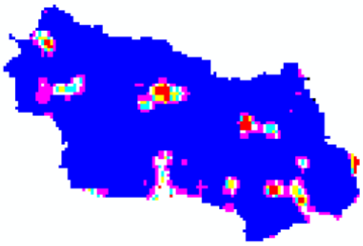
Furthermore, the radiance values data was compared to the data which represents the population, GDP, and energy consumption development for the same period of time, to see if there is correlation between those data and how the VIIRS data developed.

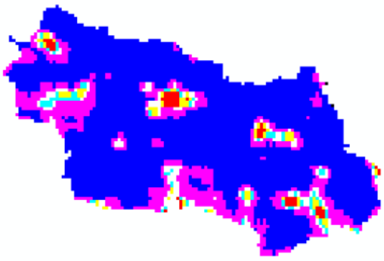
# 6. RESULTS

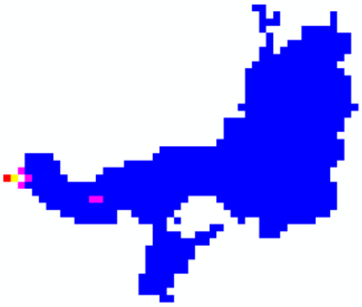
Results show us that there was change in radiance values of VIIRS data between 2014-2022, with the upward tendency, both for the area of whole country and individual national parks.











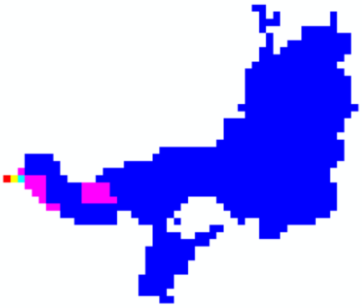


Figure 7. Visualization of temporal change in radiance values for national parks in Czech Republic. From left to right 2014 – 2022, From up to down: Šumava, Podyjí, Krkonoše, České Švýcarsko

From taking looking at the figure 7 it is noticeable at the first glance that the bright areas which represent the higher radiance values, take more area of the national parks in 2022 than in 2014 which immediately tells us that there was a growth. Same situation is when we take a look at the country as whole.

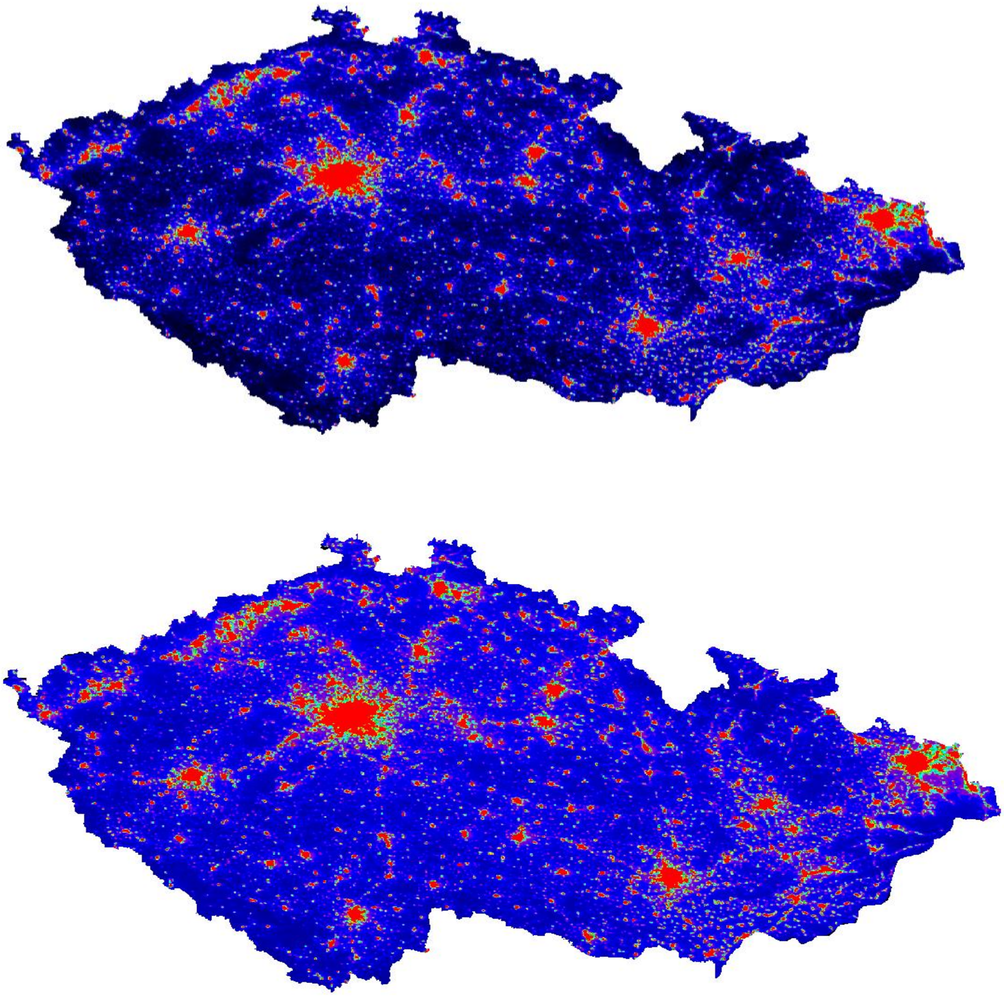


Figure 8. Visualization of the VIIRS values for the whole area of Czech Republic, 2014 up and 2022 down

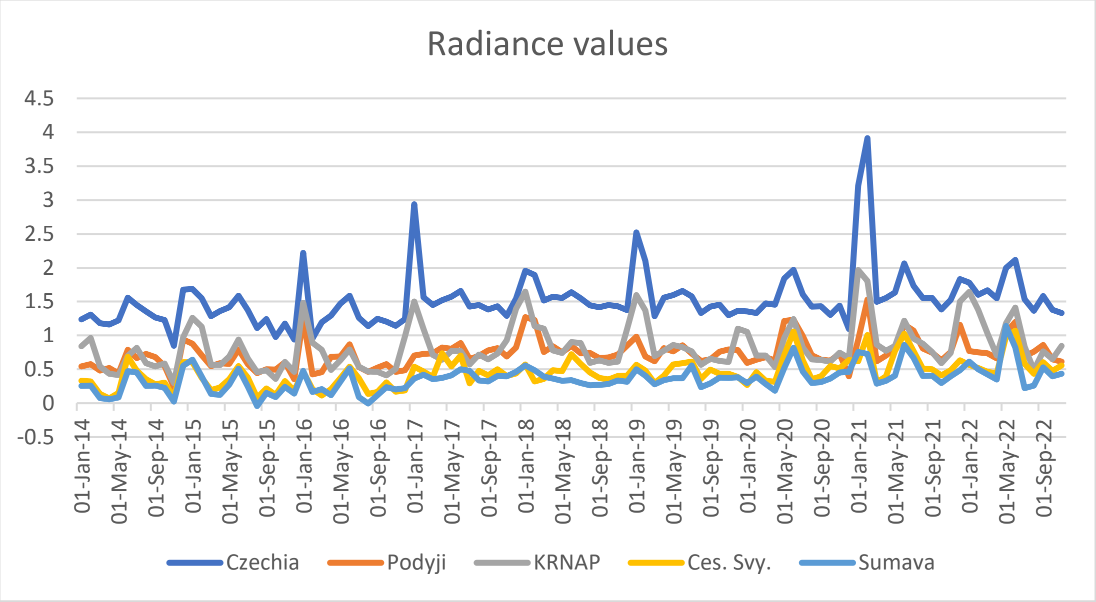


Figure 9. Graphical representation of the fluctuation of the radiance values for the country and each national park between 2014-2022

Figure 9 shows us that even though, national parks have lower values than the whole country the pattern is very similar, as there is a slight upward trend with the very noticeable peaks, which occur most of the time around January 1st, which makes sense knowing that at that time there are a lot of light decorations and fireworks due to new year celebration. Also, higher values during the winter months can be explained by the fact that night is longer and there is increased need for artificial lighting compared to summer months.

Further the data was investigated for correlation between it’s development and factors such as population, energy consumption and GDP.

| | Energy cons. | Population | GDP |
|---|---|---|---|
| Czech Republic | 0.526 | -0.102 | 0.804 |
| Podyjí | 0.400 | 0.121 | 0.846 |
| Krkonoše | 0.591 | -0.115 | 0.881 |
| České Švýcarsko | 0.154 | 0.069 | 0.924 |
| Šumava | 0.175 | -0.001 | 0.923 |

Table 1. Correlation between the development of radiance values and development of outside factors which may be the cause of such development

From look at the table 1 we can conclude that there is a strong positive correlation between the development of GDP (Gross Domestic Product) (Czech Republic GDP, n.d.) and the radiance values, weak to moderate positive correlation with Energy consumption (Energetická bilance ČR - časové řady, n.d.), and no significant correlation with population growth (Population and vital statistics - selected territory, n.d.).

# 7. DISCUSSION

The aim of this thesis was to determine how the night light pollution developed over the national parks of Czech Republic during the period of 2014-2022.

Results imply that, even though not very sharp, there still exists the positive trend in regards to rising of the radiance values, both in Czech Republic as whole and national parks each separately. By comparing the data to other factors, it can be concluded that the driving factor behind the development of night light pollution is GDP. As the country develops, we can assume that this trend will continue to go upward.

If we take a look at national parks alone, we are shown that the one which is most impacted by the light pollution is the Krkonoše NP. This is caused by it being one of the most popular winter tourism destinatnions in Czech Republic. This may be cause for concern between environmentalists, not just in regards of light pollution, but also other types of it. In future special attention should be put towards the examination of light pollution in this national park.

# 8. CONCLUSION

Minimizing night pollution, or artificial light at night (ALAN), is a critical step in reducing the negative impacts of light pollution on the environment and human health. To achieve this, several strategies can be employed, including responsible lighting practices, light fixture design, and urban planning. By employing these strategies, we can minimize the amount of light emitted into the sky and reduce light trespass, glare, and skyglow.

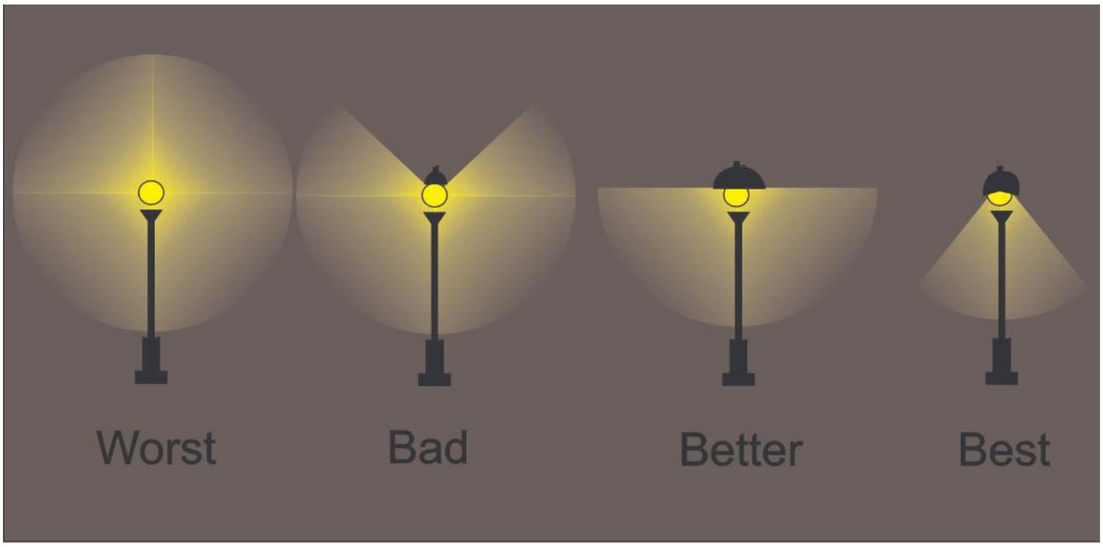


Figure 10. Types of street light (Light Pollution, n.d.)

It is essential to raise awareness about the importance of minimizing night pollution and its impact on the environment and human health. Through education and outreach, we can promote the adoption of responsible lighting practices and encourage individuals and businesses to take steps to reduce their contribution to light pollution.

1. There are 5 general principles of correct lighting according to SIMPLE LIGHTING GUIDE - Recommendations for gentle modern lighting created by The Ministry of the Environment of the Czech Republic (Jednoduchá Osvětlovací Příručka, 2021):

   1. Shine only where needed. Do not shine into people's windows, the surrounding landscape, or the sky, do not illuminate trees and bodies of water.

   2. Only shine down, use fixtures appropriate for the situation and do not tilt them. Consider carefully where it is best to install the lights.

   3. Do not shine unnecessarily brightly and use the option to dim the light

when there is little traffic. If the lighting is not needed, turn it off or dim it to a minimum.

4. Use warm shades of light. The chromaticity temperature shouldn’t exceed 2700 K.

5. Ask the designer and supplier for gentle lighting.

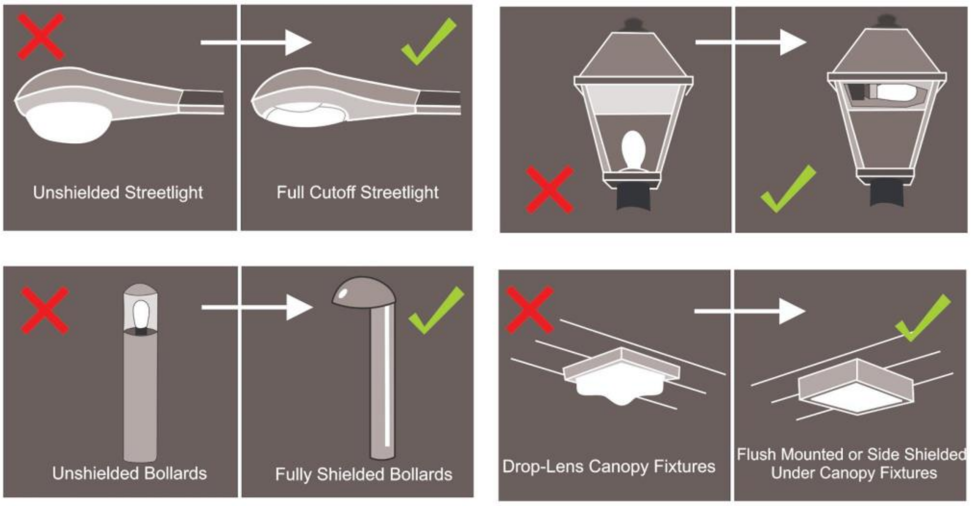


Figure 11. How the artificial light emitters should be designed like to reduce light pollution (Light Pollution, n.d.)

In conclusion, minimizing night pollution is an urgent need that requires collaborative efforts from policymakers, city planners, lighting designers, and the general public. By employing responsible lighting practices, proper fixture design, and urban planning, we can reduce the negative impacts of light pollution on the environment and human health and preserve our natural resources for future generations.

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