Light pollution analysis in Lombardy: a change detection approach

Earth Observation 2024 - Module B

Emma Lodetti - 10619244[1,⋆]

[1] *Politecnico di Milano, Geoinformatics Engineering*
GitHub repository: Light-pollution-analysis

Abstract Light pollution is one of the emerging pollutants in the field of environmental damage. It is the direct consequence of urban development, the growth of cities, and population growth. NASA's Black Marble nighttime lights product suite (VNP46) is suitable for studying this phenomenon and its trend over time. It has been available at 500 m resolution since January 2012. Data are retained from the Visible Infrared Imaging Radiometer Suite (VIIRS), on board the Suomi-National Polar-orbiting Partnership (S-NPP) and Joint Polar Satellite System (JPSS) satellite platforms. In particular, the Day/Night Band (DNB) sensors provide global daily measurements of nocturnal visible and near-infrared (NIR) light that is suitable for earth system science and applications studies [1]. This study aims to analyze changes in light pollution in the Lombardy region of Northern Italy from April 2019 to April 2024. Data processing was conducted using the BlackMarbleR package [2], which provides a simple way to use nighttime light data from NASA's Black Marble. Change detection was performed with QGIS `OTB MultivariateAlterationDetector`.

1 Introduction

Urbanization is increasing worldwide [3]. Pollution is the direct consequence of this phenomenon, and, in particular, light pollution could be taken as a good indicator of urban development.
Light pollution is a type of pollution that is called over-illumination of an environment by artificial light [4]. The invasion of artificial light has exerted an adverse impact on astronomical observation, human health, ecological environment, and physiology of plants and animals [5].
This study aims to analyze how light pollution has changed in the last five years. The research concentrated in northern Italy, in particular in the Lombardy region, interested by an intense process of urbanization and peri-urbanization [6].

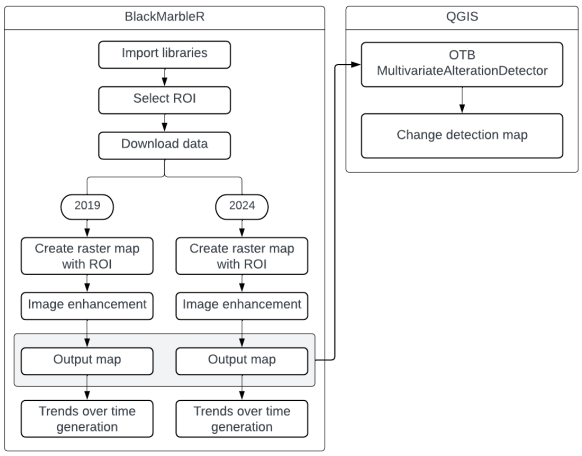

Figure 1. Workflow of the analysis.

2 Materials and Methods

To study the development of light pollution in the Lombardy region, in Northern Italy, in the last five years, the NASA Visible Infrared Imaging Radiometer Suite (VIIRS) has been used. In particular, Black Marble is a daily calibrated, corrected for atmospheric, terrain, vegetation, snow, lunar, and stray light effects, and validated product, in which cloud-contaminated pixels have been removed.
NASA's Black Marble nighttime lights product suite (VNP46) is available at 500m resolution since January 2012 [1]. Data are collected by the VIIRS instrument, a component of the Suomi National Polar-orbiting Partnership (NPP) satellite.

VIIRS consists of 22 spectral bands from the ultra-violet to the mid-infrared, one of which is able to observe nighttime lights, the Day/Night Band (DNB). **DNB is a panchromatic band** sensitive to visible and near-infrared wavelengths. All the Black Marble products available can be found in Table 1.
All these products, except for Black Marble HD (on demand), can be downloaded from the Level-1 and Atmosphere Archive and Distribution System Distributed Active Archive Center (LAADS DAAC), which archives and distributes data on clouds, water vapor, and aerosols in Earth's atmosphere.

⋆emma.lodetti@mail.polimi.it

Product ID	Geographic Coverage	Spatial Resolution	Temporal Resolution	Availability
VNP46A1	Global	15 arc second	Daily	< 1day
VNP46A2	Global	15 arc second	Daily	< 1day
VNP46A3	Global	15 arc second	Monthly	1 week
VNP46A4	Global	15 arc second	Annual	1 week
Black Marble HD	Local-to-Regional	≤ 30 m	Daily/Monthly/Annual	< 1 week
Black Marble NRT	Global	15 arc second	Daily	< 1 day

Table 1. Available Black Marble products.

Figure 1 describes the workflow followed to achieve the goal of this study. It is articulated into two main processes, using two different tools:

1. **BlackMarbleR package** for downloading and processing images, creating raster maps, and computing trends over time.

2. **QGIS** for performing change detection.

2.1 BlackMarbleR package

The first part of the analysis was conducted through the usage of **BlackMarbleR** [2], an R package that provides a simple way to use nighttime lights data from Black Marble. This package automates the process of downloading all relevant tiles from the NASA LAADS DAAC to cover a Region Of Interest, converting and mosaicing the raw files (originally in HDF5 format) to georeferenced rasters [2].

2.1.1 Region Of Interest selection

The Region Of Interest (ROI), in the WGS84 (epsg:4326) coordinate reference system, has been defined with GADM data, which provides maps and spatial data for all countries and their sub-divisions.
ROI selection allows the production of a map that is perfectly cropped in the study area.

2.1.2 Data download

The NASA LAADS Archive provides daily, monthly, or annual updated data (a Bearer Token is required), with different levels of processing:

- **VNP46A1** Daily raw data
- **VNP46A2** Daily corrected data
- **VNP46A3** Monthly data
- **VNP46A4** Annual raw data

Data can be downloaded directly from R code, by entering the date, the product code, and the required token.
For change detection, April 2019 and April 2024 monthly (VNP46A3) data were considered for this analysis. In addition, the entire five-year period was analyzed, through the usage of monthly April data for each year. This moment of the year has been chosen due to the lack of important festivities or vacation periods.

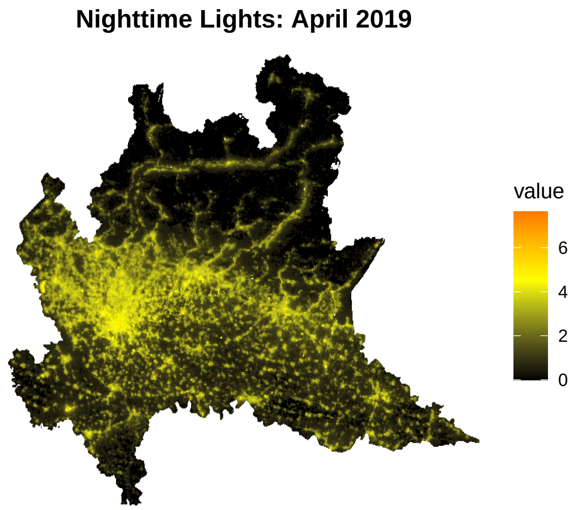

Figure 2. Nighttime lights map for April 2019.

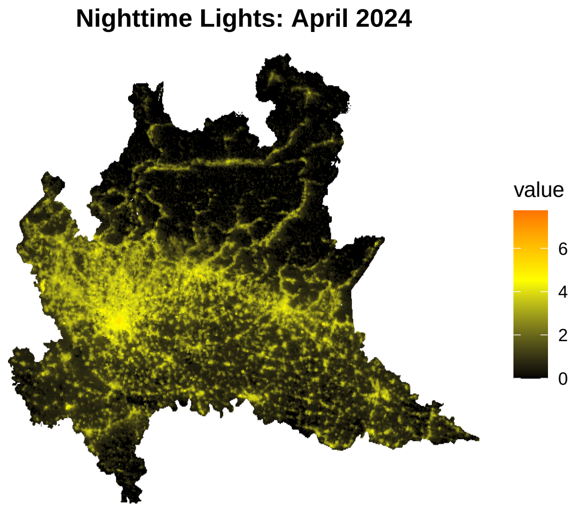

Figure 3. Nighttime lights map for April 2024.

2.1.3 Raster map creation and Image enhancement

Raster maps have been created by cropping downloaded data on the ROI previously defined (subsubsection 2.1.1). The distribution of the pixels values resulted skewed, so a logarithmic transformation is needed to enhance the images and make further analysis clearer.

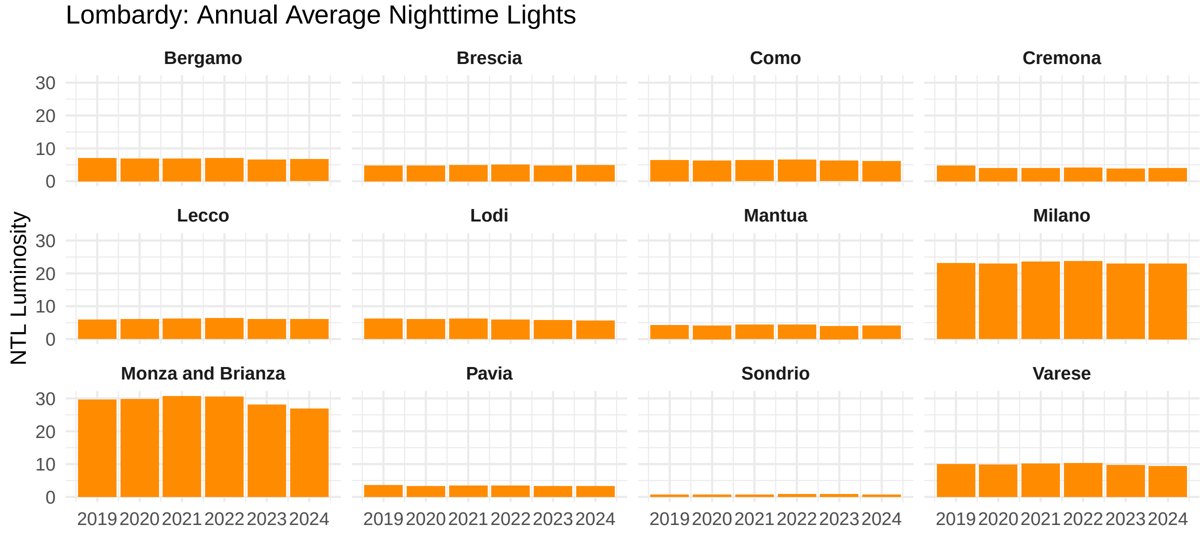

Figure 4. Trend over time in Lombardy region.

2.1.4 *Output maps and data visualization*

The outputs of the first part of the analysis have been directly visualized in R, as shown in Figure 2 for April 2019 and in Figure 3 for April 2024.
The luminosity is measured in L_{NTL} (units of $nWatts \cdot cm^{-2} \cdot sr^{-1}$).

2.1.5 *Trend over time*

As explained in subsubsection 2.1.2, monthly April data for each year, from 2019 to 2024 has been used to compute a trend over time, in order to highlight the changes in time of light pollution in Lombardy.
The analysis has been conducted considering the Lombardy subdivision in provinces, as shown in Figure 4. The unit of measurement is L_{NTL}, as cited in subsubsection 2.1.4.
It can be noticed that light pollution over the years has been quite constant in all the provinces of Lombardy. The maximum Luminosity has been reached during the years 2021 and 2022 after the COVID-19 pandemic emergency.

2.2 Change detection in QGIS

After importing in QGIS nighttime light maps of April 2019 and April 2024, change detection has been performed using spectral differences with the `OTB MultivariateAlterationDetector`. As explained in the documentation, it uses the Multivariate Alteration Detector (MAD) algorithm, which produces a set of N change maps (where N is the maximum number of bands in the first and second input images). In this case, a single band was used for both 2024 and 2019 layers, so it has been obtained a single change detection map.
The result of the study is pictured in Figure 5. In red pixels, where the difference between the 2024 image and the 2019 image is positive, light pollution is increased, otherwise, in dark blue pixels, the phenomenon is decreased. Among these two cases, in all the pixels having a color in between, light pollution remains quite constant.

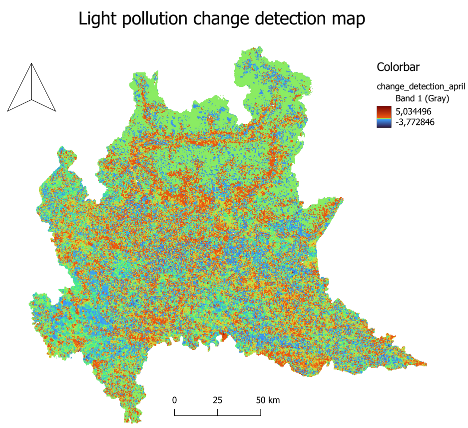

Figure 5. Light pollution change detection map.

3 Results discussion

BlackMarbleR nighttime light maps from April 2019 and April 2024 show slight changes in light pollution amount. The area of Milan, in Figure 6, can be taken as an example.
The city center appears very similar in the two different years, with a minor decrease in luminosity. Instead, in Milan's north hinterland municipalities, light pollution has increased in 2024. These observations can be validated by analyzing the change detection map: Milan's city center appears green, and Milan's north hinterland pixels are red (Figure 6). This trend can also be observed in Figure 4: light pollution in the Milan area has slightly decreased on average in 2024 with respect to 2019.
An increasing light pollution can be noticed in northern Lombardy, in the mountainous area of the region. 2024

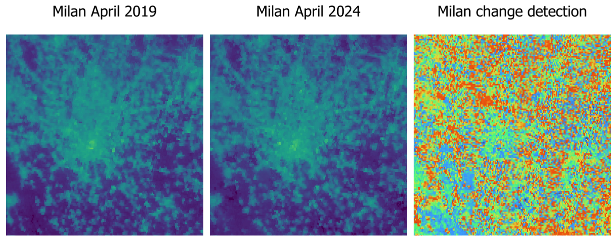

Figure 6. QGIS comparison between 2019 and 2024 light pollution in Milan.

had a long and profitable winter season due to the large and late snowfalls. It can be assumed that the increased light pollution in this area has been due to skiing and hiking tourism.
Pixels of different colors are mixed in the whole study area and a strong pattern can't be noticed. It can then be said that, in general, light pollution doesn't have a strictly increasing or decreasing trend (consistently with the result inferred from Figure 4).

4 Conclusions

A precedent study I've conducted on the urbanization of the same area showed how the build-up areas slightly increased from 2019 to 2024. The analysis was conducted by comparing Index-based Built-up Indicies (IBI) [7] computed on a region in northern Italy including the cities of Milan, Bergamo, and Brescia.
The biggest cities in Lombardy had quite imperceptible growth, in contrast to the areas outside these cities, where urbanization is more noticeable, as can be seen in Figure 7, where is pictured Milan's north-western hinterland area.

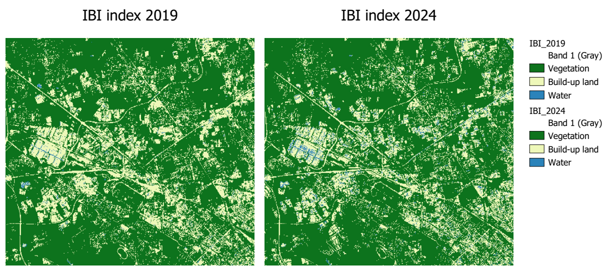

Figure 7. QGIS comparison between 2019 and 2024 IBI index in north-west area outside Milan.

The results obtained from this light pollution analysis don't seem to be revolutionary but highlight two main factors:

- **Light pollution remains constant or sightly decreases in the city centers but grows in the hinterland areas.** In the last few years, people started to migrate outside the large urban centers and stabilize in mid or small municipalities, also due to the increasing usage of smart working during and right after the pandemic emergency.

  This may be a reason why light pollution increased in rural areas.
- **Light pollution has not grown despite the (mild) urbanization growth.** Norms and measures have been applied to limit this phenomenon: outdoor lighting fixtures that shield the light source, dimmers, motion sensors, timers, laws and simply greater sensitivity to this themes.

In conclusion, the policies defined by the Lombardy region are showing good results. On the other hand, the increasing number of people leaving the cities is worsening the situation in rural areas.
It would be interesting to improve the study of the behavior of each city and analyze a potential correlation between urbanization and light pollution changes in further research.

References

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