Satellite Open Data for Smart City Services Development

Details on methodology, algorithms and validation techniques of the Digital Services

Index

Version	***Date***	***Notes***	***Author***
1.0	22/01/2024	Initial release	Latitudo 40
2.0	26/02/2024	Added Appendix and details on the methodologies	Latitudo 40
2.1	18/06/2024	Minor fix and updates	Latitudo 40

SPOTTED - Funded by the European Commission under the Connecting Europe Facilities (CEF) program-Horizon2020

Urban Heat Exposure

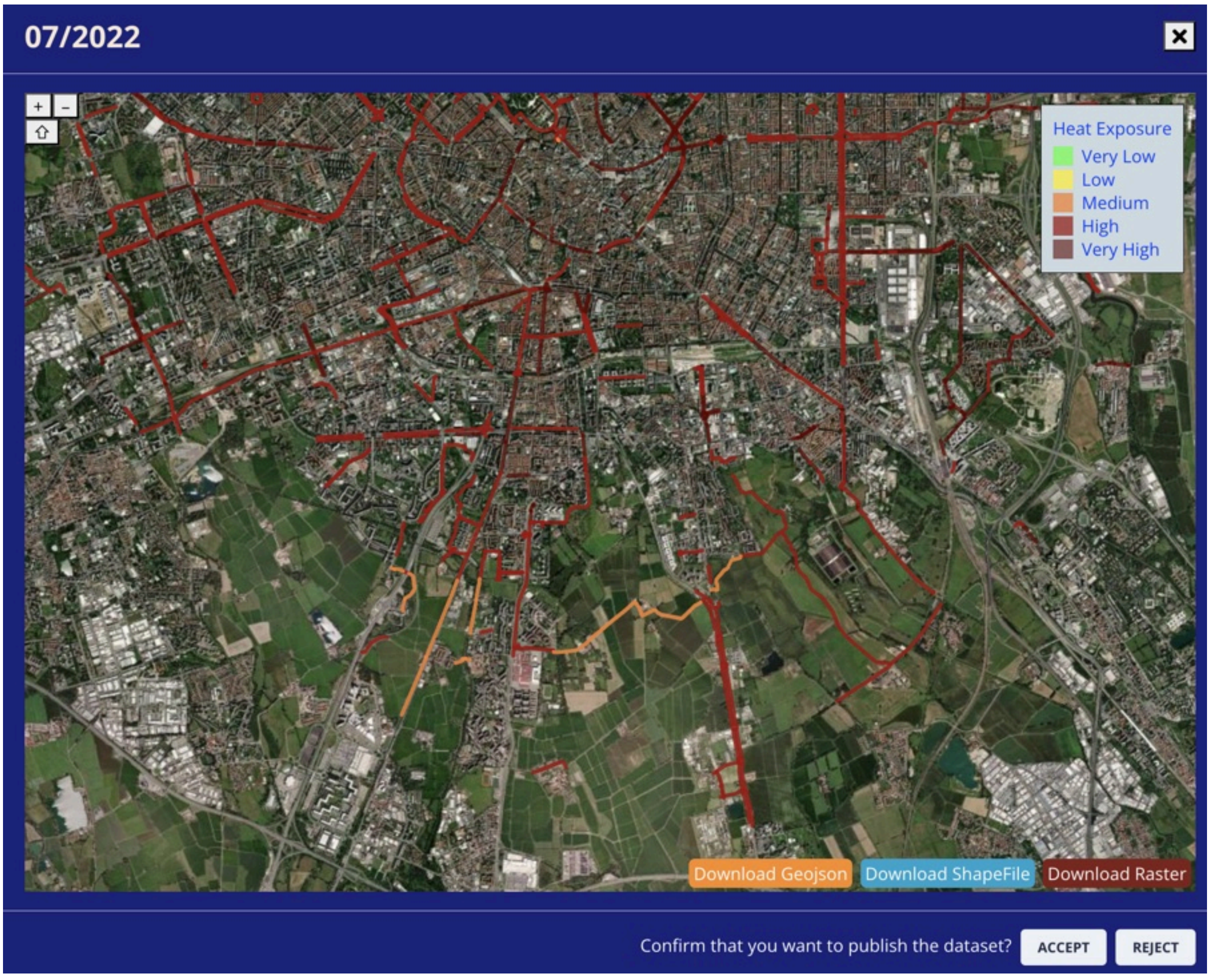


Figure 1: Urban Heat Exposure for Bike Paths in the Municipality of Milan

Overview

Urban Heat Exposure calculates the heat exposure of different urban objects and features. These can be points, lines, and polygons. The Urban Heat Exposure product allows monitoring of the heat island phenomenon by highlighting areas that become hotter than surrounding rural areas due to human activities such as urbanization. A percentage index is generated by analyzing ground temperature data from 0 to 1, where higher values indicate greater exposure to the phenomenon, thus locating critical areas.

Input data

SPOTTED - Funded by the European Commission under the Connecting Europe Facilities (CEF) program-Horizon2020

SOURCE	RESOLUTION (m)	UPDATED	NOTES
Sentinel-2 (satellite)	10	weekly	used for LST computation
Modis (satellite)	1000	daily	used for LST computation
Landsat (satellite)	30	biweekly	used for LST computation

Methodology

Urban Heat Islands are computed by determining the magnitude of the difference between the urban area land surface temperature (LST) and a reference LST. This reference LST is computed based on a rural area, serving as a baseline for comparison.
In the context of computing Urban Heat Exposure, rural areas typically refer to regions characterized by low population density, sparse human infrastructure, and predominantly natural landscapes such as farmland, forests, or grasslands. In terms of Urban Heat Islands, rural areas are often identified by their lack of significant urban development, which leads to lower levels of impervious surfaces (e.g., roads, buildings, pavements) and reduced anthropogenic heat emissions compared to urban areas.

An automatic methodology was developed to identify rural areas using land cover classification (LC) and tree cover density (TCD) as masks.
The LC map filters out areas different from greenery or agricultural land cover types. The algorithm identifies rural areas, ranking remaining areas regarding (i) tree canopy cover (ii) and population density. Areas with low population density and significant tree canopy cover are labeled as rural areas.
The LST used for the computation is downscaled to a 10 m spatial resolution using Sentinel-2 and Landsat-8/9 satellite imagery.

Finally, the UHI, ranging from 0 to 100, is derived by applying the simple formula:

$$UHI\ Intensity_{pixel} = LST_{pixel} - LST_{rural}$$

where LST_{rural} is the median temperature of the rural area.
Next, a normalization process is carried out:

SPOTTED - Funded by the European Commission under the Connecting Europe Facilities (CEF) program-Horizon2020

$$UHI_{pixel} = \frac{UHI\ Intensity_{pixel} - min(UHI\ Intensity)}{max(UHI\ Intensity) - min(UHI\ Intensity)} \times 100$$

Metrics and Results

This product results from a procedural algorithm, so validation reference has been made to the LST layer produced. LST was compared with (i) very-high spatial resolution thermal data acquired from airplane flights (ii) and thermal data from ground sensors. The first refers to an acquisition made at the end of January 2023 in the Municipality of Milan. The second refers to ground data from 2018 to 2022 from sensors installed near Photovoltaic Plants in Italy.

Spotted Portal - Visualization

The provided legend indicates heat exposure levels with a color gradient from green to dark red. Each color represents a specific range of heat exposure, with intervals from 0 to 1, increasing by 0.2 for each level.

Here’s the breakdown of the legend:

1. **Very Low Heat Exposure (Green)**:
   - Color: Green
   - Interval: 0.0 to 0.2
   - Description: This range represents minimal heat exposure.
2. **Low Heat Exposure (Yellow)**:
   - Color: Yellow
   - Interval: 0.2 to 0.4
   - Description: This range indicates a slightly higher, but still relatively low, level of heat exposure.
3. **Medium Heat Exposure (Orange)**:
   - Color: Orange

SPOTTED - Funded by the European Commission under the Connecting Europe Facilities (CEF) program-Horizon2020

- Interval: 0.4 to 0.6
- Description: This range signifies a moderate level of heat exposure.

4. **High Heat Exposure (Red)**:
   - Color: Red
   - Interval: 0.6 to 0.8
   - Description: This range represents a high level of heat exposure.
5. **Very High Heat Exposure (Dark Red)**:
   - Color: Dark Red
   - Interval: 0.8 to 1.0
   - Description: This range indicates the maximum level of heat exposure, representing very high heat conditions.

Areas of Application

The Urban Heat Exposure product is derived from the Land Surface Temperature and allows for information on heat islands, thus not just temperature. The main application areas identified are:

- Urban planning: Analysis of urban areas that suffer most from the heat island phenomenon to identify efficient and effective mitigation strategies.
- Health: Using the index to predict areas of potential heat-related health risk to guide medical preparedness and public health campaigns.
- Energy efficiency: Predict peak energy demand in heat-affected areas, ensuring grid stability and efficient distribution.

References

Fabrizi, Roberto, Stefania Bonafoni, and Riccardo Biondi. "Satellite and ground-based sensors for the urban heat island analysis in the city of Rome." Remote sensing 2.5 (2010): 1400-1415.

Ryu, Young-Hee, and Jong-Jin Baik. "Quantitative analysis of factors contributing to urban heat island intensity." Journal of Applied Meteorology and Climatology 51.5 (2012): 842-854.

Zhang, Yang, et al. "Study on urban heat island intensity level identification based on an improved restricted Boltzmann machine." International journal of environmental research and public health 15.2 (2018): 186.

Wu, Xiangli, Lin Zhang, and Shuying Zang. "Examining seasonal effect of urban heat island in a coastal city." PLoS One 14.6 (2019): e0217850.

SPOTTED - Funded by the European Commission under the Connecting Europe Facilities (CEF) program-Horizon2020

Urban Heat Wave Risk

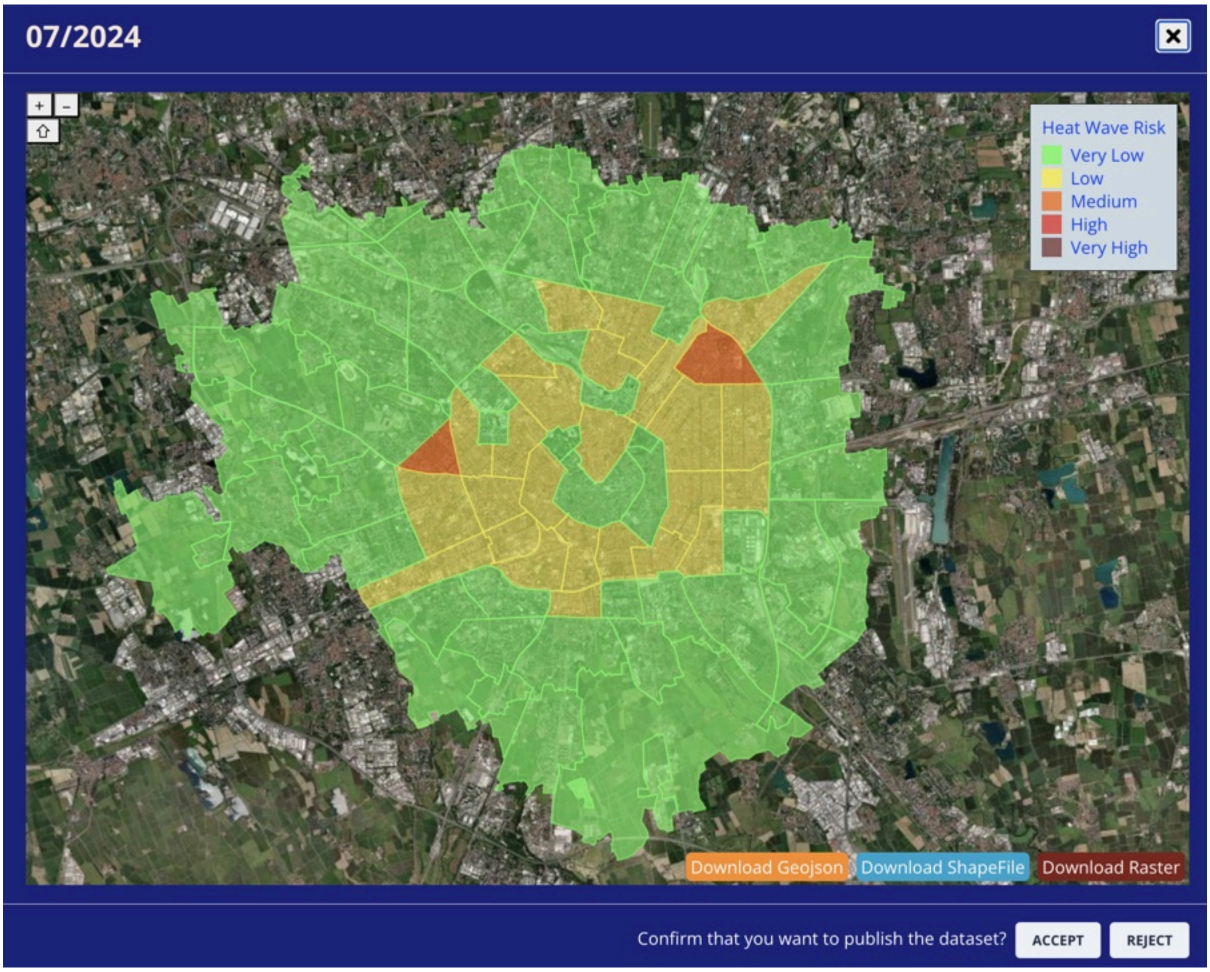


Figure 2: Urban Heat Wave Risk for the NIL (districts) of the Municipality of Milan

Overview

Heat waves are considered among the natural disasters with the greatest impact on health, causing numerous casualties and having devastating effects on ecosystems in general. The climatic situation currently affecting our planet is favoring an increase in the frequency and intensity of heat waves even in advance of the typically warm period, thus exposing more and more people to this risk. These impacts are exacerbated in cities due to the Urban Heat Island (UHI) effect and the high and increasing concentration of people, goods and economic activities. Unfortunately, future climatological projections also predict much more drastic scenarios than the current ones, with intense and persistent effects over large areas

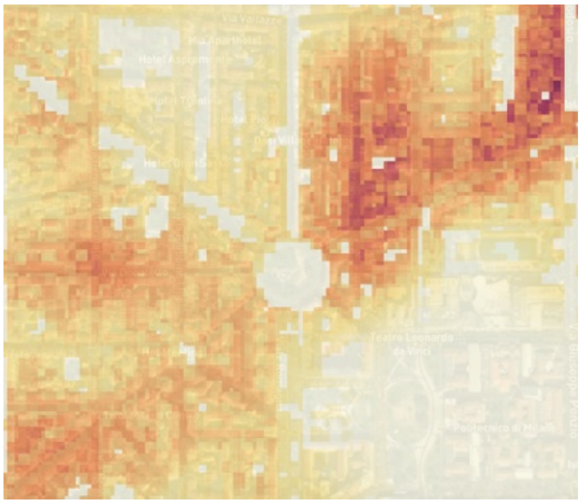
SPOTTED - Funded by the European Commission under the Connecting Europe Facilities (CEF) program-Horizon2020

of the planet. Mitigation actions and adaptation strategies to ongoing climate change are therefore increasingly crucial, with particular attention to the urban environment where most of the population is concentrated.
The Urban Heat Wave Risk is obtained by combining data on temperature (hazard), population by age group (exposure) and morphological characteristics of the area (vulnerability). This product makes it possible to derive a risk index (between 0 and 100) where values close to zero are risk-free, while values close to 100 identify the most critical areas to be prioritized. The following table shows the calculation of Heat Wave Risk (HPR) Map for the cities of Milan and Naples for the year 2023.

	
HPR in the city of Milan for the year 2023	*HPR in the city of Naples for the year 2023*

The data produced over the entire city, or more generally for the area of interest, makes it possible to highlight which areas are more or less at risk. Obviously, it is possible to go into more detail as the spatial resolution of 10 meters allows. As can be seen in the following images, it is possible to get a detail of the heat island risk for the individual building.

SPOTTED - Funded by the European Commission under the Connecting Europe Facilities (CEF) program-Horizon2020

	
ESRI Imagery over an area of the city of Milan	*Urban Heat Wave Risk over an area of the city of Milan for the year 2023*

Input data

SOURCE	RESOLUTION (m)	UPDATED	DESC
UHI	10	monthly	Hazard
Building height	10	2012	Vulnerability
Population density	100	2022	Exposure

Methodology

The risk of high and potentially extreme temperatures in urban areas therefore, requires consideration of multiple factors, including the frequency and severity of heat events (Jenkins et al., 2014), the degree of population exposure, and vulnerability due to the morphology and materials of the city. Risk assessment is thus the first step in establishing a methodology that aims to evaluate the effectiveness of mitigation and adaptation strategies to climate extremes.

Qualitative and quantitative definitions of risk, through identifying its components and the relationship between them, are numerous. The best known is the one adopted in 1972 by UNESCO in the "Convention Concerning the Protection of the World Cultural and Natural Heritage" (UNESCO, 1972), which defines "risk" as a combination of three components:

SPOTTED - Funded by the European Commission under the Connecting Europe Facilities (CEF) program-Horizon2020

Hazard, Exposure and Vulnerability. This approach has been used for spatial risk assessment in other contributions, such as Tomlinson et al., 2011: "The methodology utilized in this paper has deliberately been kept simple and transparent in order to remove excessive complicated jargon and help explanation to stakeholders including local authorities," using a stratification system in GIS.

Hazard (H - Hazard)
Hazard is defined as the probability that a hazardous phenomenon of a given intensity (I) will occur within a given time period and in a given area. It may cause loss of life, injury or other health impacts, property damage, loss of livelihood and services, social and economic hardship, or environmental damage. Hazards may be single, sequential, or combined in origin and effect. In this case, the hazard is the Urban Heat Island, which is calculated as the average of the summer months of the year under review.

Exposure (E - Exposure)
Exposure is defined as the number of units (or "value") of each of the elements at risk in a given area: it can be expressed as the number of human presences or as the value of economic and natural resources that are exposed to a given hazard and that may be lost in the event of a destructive event. In this case, since we are in an urban context, exposure is calculated as a function of population density in different areas of the city and the spatial distribution of age groups, considering that children and the elderly are more exposed to the health risks associated with extreme temperatures (Tomlinson et al., 2011). Given the need to make the whole process replicable for any case study, the WorldPop database (https://hub.worldpop.org) was used as a source of population density. The "Constrained individual countries 2020" layer estimates the total number of people per pixel divided by sex and age groups (including 0 to 1 year and 5 years to 80+) in 2020 at a resolution of 100 m. In particular, age groups susceptible to UHI were considered: children under 10 years old and the elderly aged 65+. The exposure layer is the result of summing the thresholds for each year and shows the density of the vulnerable age groups listed above.

Vulnerability (V - Vulnerability).
Vulnerability is defined in the literature as the loss produced by a certain element or group of elements exposed to the risk of the occurrence of a phenomenon of a certain intensity. It is also defined as "susceptibility to damage." The aspects of vulnerability are many and arise from various physical, social, economic and environmental factors. Examples include poor building design and construction, inadequate asset protection, lack of public information and awareness, limited official recognition of hazards and preparedness measures, and failure to follow wise environmental management. Vulnerability varies significantly within a community and over time (Turnbull et al., 2014). In the context of urban areas, considering extreme temperatures as a hazard, some parameters that emphasize impacts can be related to

SPOTTED - Funded by the European Commission under the Connecting Europe Facilities (CEF) program-Horizon2020

materials, impervious surfaces, urban morphology, and shading. Each thematic layer was given a qualitative score, and then all were combined to obtain an aggregate map of vulnerable areas.
The final variables consist of four layers:

- Built-up area;
- Building density;
- Sky View Factor;
- Shadow Depth, calculated on July 30 of the year under study, at 8:00 a.m., 10:00 a.m., 12:00 p.m., 2:00 p.m., 4:00 p.m., 6:00 p.m., and averaged.

Once the three maps of Hazard, Exposure and Vulnerability are derived, the risk layer can be obtained by simply multiplying the three factors:

$$R = H \times E \times V$$

Metrics and Results

Because this product is derived from a procedure that aggregates several data sources, and because there is no Ground Truth available, the goodness and accuracy of the results can be attributed to the data used as input by the pipeline for the calculation.

Spotted Portal - Visualization

The provided legend indicates different levels of heat wave risk, ranging from very low to very high. Each color corresponds to a specific risk interval from 0 to 1, with each interval increasing by 0.2.

Here’s a detailed description of the legend:

SPOTTED - Funded by the European Commission under the Connecting Europe Facilities (CEF) program-Horizon2020

1. **Very Low Heat Wave Risk (Green)**:
   - **Color:** Green
   - **Interval:** 0.0 to 0.2
   - **Description:** This range represents areas with minimal risk for people during a heat wave.
2. **Low Heat Wave Risk (Yellow)**:
   - **Color:** Yellow
   - **Interval:** 0.2 to 0.4
   - **Description:** This range indicates areas with a slightly higher, but still relatively low, risk for people during a heat wave.
3. **Medium Heat Wave Risk (Orange)**:
   - **Color:** Orange
   - **Interval:** 0.4 to 0.6
   - **Description:** This range signifies a moderate risk of heat waves, meaning there is a balanced risk for people during a heat wave.
4. **High Heat Wave Risk (Red)**:
   - **Color:** Red
   - **Interval:** 0.6 to 0.8
   - **Description:** This range represents areas with a high risk of heatwave conditions, suggesting a strong likelihood of risk for people during a heat wave.
5. **Very High Heat Wave Risk (Dark Red)**:
   - **Color:** Dark Red
   - **Interval:** 0.8 to 1.0
   - **Description:** This range indicates the highest risk level, where heat wave conditions are very likely to affect people in the area.

Areas of Application

The Heat Wave Risk Map can be used in several application areas including:

- Emergency Services: Develop strategies and responses for regions most prone to heat waves, ensuring rapid responses.
- Insurance: Incorporate comprehensive heat wave risk assessments to create more accurate policies.
- Health Care: Understand areas with vulnerable populations, such as children and the elderly, to better prepare for heat wave-related health problems.
- Real Estate: Use heat wave risk data to determine areas suitable for development and ensure safety.

SPOTTED - Funded by the European Commission under the Connecting Europe Facilities (CEF) program-Horizon2020

References

Gruber, Stefan. "Convention concerning the protection of the world cultural and natural heritage 1972." Stefan Gruber,‵Convention concerning the Protection of the World Cultural and Natural Heritage. 1972.

Jenkins, Katie, et al. "Probabilistic spatial risk assessment of heat impacts and adaptations for London." Climatic change 124 (2014): 105-117.

SPOTTED - Funded by the European Commission under the Connecting Europe Facilities (CEF) program-Horizon2020

Urban Green Index

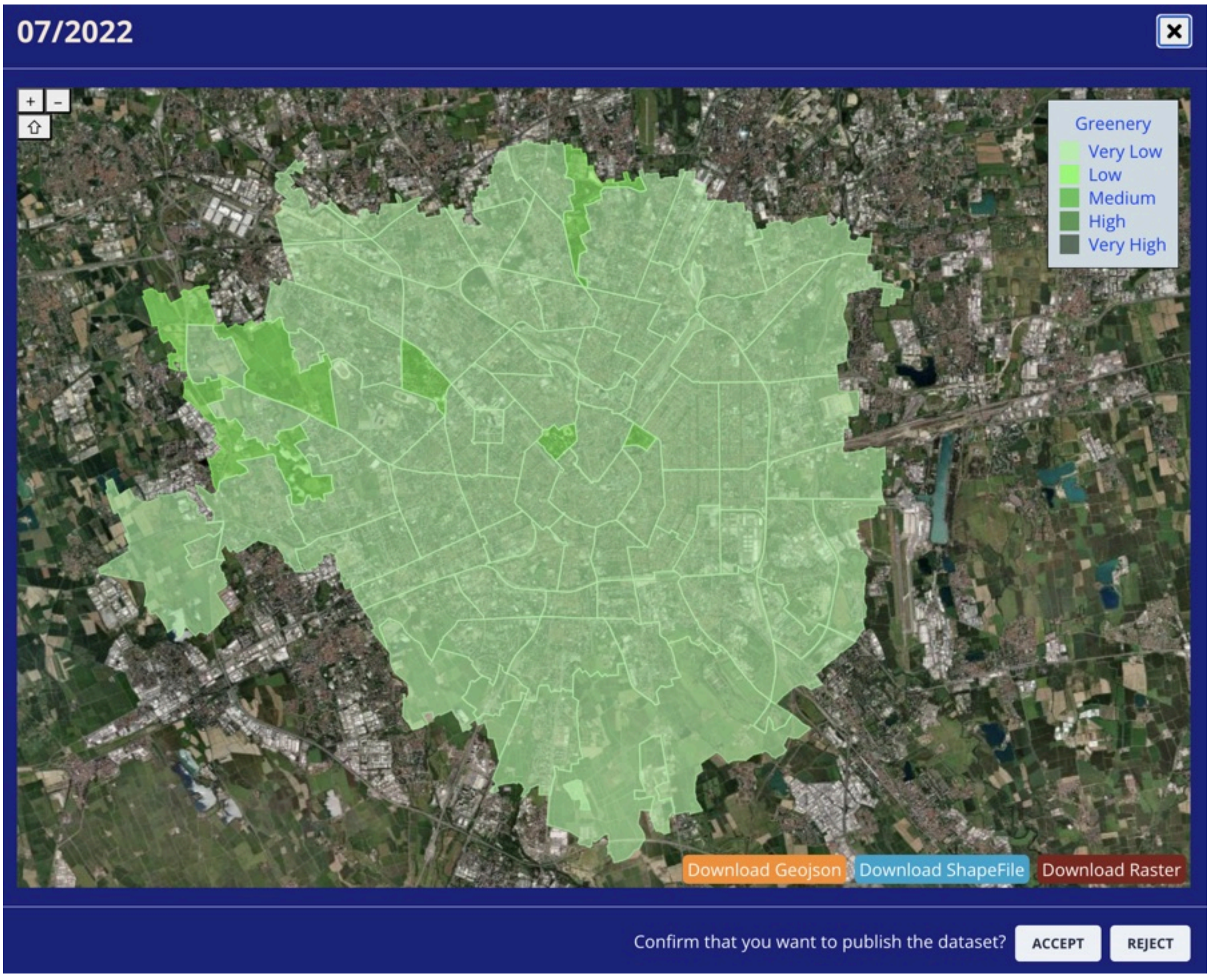


Figure 3: Urban Green Index computed for some of the NIL (districts) in the Municipality of Milan

Overview

The Urban Green Index, or Green Cover Index, is a parameter that indicates the degree of vegetation in a specific area, measured through a time-series analysis of the Normalized Difference Vegetation Index (NDVI). This index ranges from 0 to 100, where higher values indicate a greater presence of healthy vegetation. Used to monitor vegetation amount and health, the Green Cover Index is particularly useful in urban and rural areas to assess the impacts of environmental policies, level of urbanization, and agricultural practices.

SPOTTED - Funded by the European Commission under the Connecting Europe Facilities (CEF) program-Horizon2020

Input data

SOURCE	RESOLUTION (m)	UPDATED	NOTES
Sentinel 2 (satellite)	10	weekly	to identify up-to-date greenery
DEM (digital elevation model)	30	2018	to refine the result

Methodology

The Green Index uses a systematic methodology to monitor green cover, based on the aggregation of Normalized Difference Vegetation Index (NDVI) data obtained from multispectral satellite imagery. The procedure follows these steps:

- Image Acquisition: Multispectral images from the Sentinel-2 satellite are collected. These images cover both the visible and near-infrared spectra, allowing detailed analysis of vegetation.

- Pre-processing: Images undergo correction to remove distortions due to atmospheric factors or satellite angles, in addition to radiometric calibration to ensure data accuracy.

- NDVI calculation: For each image, NDVI is calculated using the formula:

$$NDVI = \frac{(Nir + Red)}{(Nir - Red)}$$

where Nir is the near-infrared reflectance and Red is the reflectance in the red band. This index is a key indicator of the presence and health of vegetation.

- Data Aggregation: After calculating the NDVI for each image, the Green Index is derived by data aggregation of single NDVI points, applying a weighted mean. This is accomplished by averaging the NDVI over a set of images collected over a period of a year following this formula:

SPOTTED - Funded by the European Commission under the Connecting Europe Facilities (CEF) program-Horizon2020

$$GREEN\ INDEX = \frac{\sum_{I=1}^{n} w_i\ x\ NDVI_i}{n}$$

Where:

$NDVI_i$ represents the i-th NDVI index;

w_i is a weight taking into account the fractional vegetation cover

n is the total number of samples.

The NDVI values are first scaled from their typical range (-1 to 1) to a normalized 0 to 1 range and finally converted the result into a Greenery Score in [0, 100].

Metrics and Results

The Green Index is based on aggregating satellite data and NDVI, an established index to monitor greenery. The goodness of accuracy of the results depends mainly on the quality of the input data used in the calculation process. Here is a summary:

- *Quality of Input Data*: The accuracy of the Green Index is strongly influenced by the quality of the satellite data collected, including its spatial resolution and accuracy in representing plant characteristics.
- *Quantitative Assessment*: Using datasets of trees and park maps collected with in-field surveys, the correlation, e.g., the Pearson correlation, between UGI values and ground truth data of vegetation cover at the validation site was analyzed.
- *Qualitative Assessment*: the analysis of Green Index results focuses on a qualitative assessment. This involves interpretation based on experience and comparison with other environmental and satellite data sources. The qualitative assessment was conducted by comparing results with datasets of trees and parks maps collected with in-field surveys.

SPOTTED - Funded by the European Commission under the Connecting Europe Facilities (CEF) program-Horizon2020

Spotted Portal - Visualization

The provided legend depicts the levels of greenery, with a color gradient ranging from light green to dark green. Each color represents a specific range of the Greenery Score, which spans from 0 to 100 and is divided into intervals of 20 units.

Here's the breakdown of the legend:

1. **Very Low Greenery (Light Green)**:
    - **Color**: Light Green
    - **Interval**: 0 to 20
    - **Description**: This range represents areas with minimal vegetation cover or very low greenery.
2. **Low Greenery (Green)**:
    - **Color**: Green
    - **Interval**: 20 to 40
    - **Description**: This range indicates areas with low levels of vegetation cover or low greenery.
3. **Medium Greenery (Medium Green)**:
    - **Color**: Medium Green
    - **Interval**: 40 to 60
    - **Description**: This range signifies moderate levels of vegetation cover or medium greenery. These areas have a balanced presence of vegetation.
4. **High Greenery (Dark Green)**:
    - **Color**: Dark Green
    - **Interval**: 60 to 80
    - **Description**: This range represents areas with high levels of vegetation cover or high greenery.
5. **Very High Greenery (Very Dark Green)**:
    - **Color**: Very Dark Green
    - **Interval**: 80 to 100

SPOTTED - Funded by the European Commission under the Connecting Europe Facilities (CEF) program-Horizon2020

- **Description**: This range indicates areas with very dense vegetation cover or very high greenery.

Areas of Application

The Green Index is a versatile indicator with multiple applications in different sectors. Below are two main areas in which this index plays an essential role in environmental monitoring and management:

- Environmental Monitoring: The Green Index is essential for assessing trends in vegetation cover and identifying areas prone to deforestation or environmental degradation. It is a key tool for biodiversity conservation and natural resource management.

- Urban Planning and Sustainable Development: The Green Index helps promote sustainable urban planning by analyzing the balance between green and built areas in cities. It contributes to creating urban green spaces, improving quality of life and reducing environmental impact.

References

Gupta, K.; Kumar, P.; Pathan, S.K.; Sharma, K.P. Urban Neighborhood Green Index—A measure of green spaces in urban areas. *Landsc. Urban Plan.* 2012, *105*, 325–335.

Aryal, J.; Sitaula, C.; Aryal, S. NDVI Threshold-Based Urban Green Space Mapping from Sentinel-2A at the Local Governmental Area (LGA) Level of Victoria, Australia. *Land* 2022, *11*, 351.

Alex de la Iglesia Martinez, SM Labib Demystifying normalized difference vegetation index (NDVI) for greenness exposure assessments and policy interventions in urban greening.

Appendix: Terms and Definitions

- **Radiometric Calibration**: Radiometric calibration is a process used to ensure the accuracy and consistency of remote sensing data by adjusting for variations in sensor sensitivity and environmental conditions. Radiometric calibration involves correcting distortions in the recorded radiance values caused by factors such as atmospheric interference, sensor degradation, and variations in solar illumination. By applying radiometric calibration techniques,

SPOTTED - Funded by the European Commission under the Connecting Europe Facilities (CEF) program-Horizon2020

researchers can enhance the quality of satellite data and improve the accuracy of subsequent analyses.

- **Land Surface Temperature (LST)**: Land Surface Temperature refers to the temperature of the Earth's surface as measured from a satellite sensor.LST plays a crucial role in understanding the thermal behavior of urban and rural areas. Satellite sensors capture emitted thermal radiation from the Earth's surface, allowing for the estimation of LST. This information is valuable for assessing heat island effects, urban microclimates, and vegetation health. LST data is often processed and analyzed alongside other environmental variables to study heat dynamics, urban heat islands, and land cover changes.
- **Multispectral Indexes**: Multispectral indexes are derived from satellite imagery captured across various spectral bands, enabling the assessment of specific characteristics or features on the Earth's surface. These indexes are calculated by combining information from different wavelengths to extract meaningful insights about land cover, vegetation health, water content, and other environmental parameters. Examples of commonly used multispectral indexes include the Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), Soil Adjusted Vegetation Index (SAVI), Normalized Difference Water Index (NDWI), and many others. Each index serves a unique purpose.
- **Near Infrared (NIR)**: Near-infrared (NIR) radiation is a segment of the electromagnetic spectrum with wavelengths slightly longer than those of visible light but shorter than those of thermal infrared radiation. In remote sensing, NIR is particularly valuable for its ability to provide information about vegetation health and structure. Healthy vegetation reflects large amounts of NIR radiation due to the chlorophyll content in leaves, resulting in high NIR reflectance values. By contrast, non-vegetated surfaces absorb more NIR radiation. This property is exploited in various vegetation indices, such as the Normalized Difference Vegetation Index (NDVI), which compares the reflectance of NIR and visible red light to assess vegetation density and health.
- **Normalized Difference Vegetation Index (NDVI)**: The Normalized Difference Vegetation Index is a remote sensing technique used to assess the presence and health of vegetation across landscapes. NDVI is calculated from satellite imagery by measuring the difference between near-infrared (NIR) and red light reflectance. The formula for NDVI is (NIR - Red) / (NIR + Red), resulting in

SPOTTED - Funded by the European Commission under the Connecting Europe Facilities (CEF) program-Horizon2020

values ranging from -1 to 1, where higher values indicate healthier and denser vegetation.

SPOTTED - Funded by the European Commission under the Connecting Europe Facilities (CEF) program-Horizon2020