Interconnected Landscapes: Multiscale Integration of Earth Observation and GIS for Sustainable Planning

Interconnected Landscapes: Multiscale Integration of Earth Observation and GIS for Sustainable Planning

Beatrice Magagnoli[1], Francesco Axel Pio Romio[2], Lorenzo Tinti[2], Gianni Lobosco[3]

[1]University of Ferrara, Sealine Research Center, Ferrara/Italy · beatrice.magagnoli@unife.it
[2]University of Ferrara, Sealine Research Center, Ferrara/Italy
[3]Politecnico of Torino, DIST, Italy

Abstract: This study explores a multiscalar approach that integrates Earth Observation (EO) and Geographic Information Systems (GIS) to support sustainable landscape planning. Using the Po River Basin in Northern Italy as a case study, we employed open-source satellite data to identify and analyze strategic areas for potential future landscape developments. By incorporating thematic layers such as vegetation indices, soil organic content, evapotranspiration and urban heat islands, we created detailed maps for large-scale regional assessments and micro-scale focus areas. The results highlight EO-based methodologies' potential to inform data-driven decision-making, facilitating site-specific interventions that enhance ecological connectivity, mitigate environmental degradation and optimize land use planning. This research emphasizes the potential role of EO in fostering sustainable territorial management and offers a replicable framework for future applications in urban and landscape planning.

Keywords: Digital landscape, sustainable planning, Earth Observation, Geographical Information Systems, Google Earth Engine

1 Introduction

Alexander von Humboldt's ascent of Mount Chimborazo in 1802 marked a turning point in the understanding of nature, introducing the idea of an interconnected system (VON HUMBOLDT 2018). This holistic perspective laid the foundation for later approaches, such as Ian McHarg's ecological planning in the 1960s (MCCHARG 1969). Advances in remote sensing and satellite technology now extend this vision, enabling an unprecedented multiscalar interpretation of landscapes and providing planners with powerful tools for sustainable development (LOBOSCO 2023). Using the Po Basin in Northern Italy as a case study (Figure 1), the present paper presents a multiscalar methodology that integrates Earth Observation (EO) data through the open-source Google Earth Engine (GEE) platform and the latest Geographic Information System (GIS) technologies to identify potential strategic areas on the territory for future landscape transformations. Drawing on the principles of landscape ecology, we aim to provide a comprehensive framework for analyzing and managing the dynamic interactions between environmental and anthropogenic systems (LESER & NAGEL 2001) for the development of landscape projects that use inherent territorial qualities. Strategic selection and planning of environmentally fragile areas, aligned with zero land consumption goals, enhance intervention sustainability. The EU Biodiversity Strategy for 2030 aims to ensure healthy, resilient soils by 2050 through protection, restoration, and sustainable use. This research identifies relatively degraded/low-quality soils, concerning the Po Basin context, for landscape-based transformation, using datasets to support site selection and evaluation. Finally, the study highlights the limitations of Earth Observation in scaling projects to real-world conditions and the benefits of integrating commercial and open-source data.

Journal of Digital Landscape Architecture, 10-2025, pp. 219-226. © Wichmann Verlag, VDE VERLAG GMBH · Berlin · Offenbach. ISBN 978-3-87907-754-0, ISSN 2367-4253, e-ISSN 2511-624X, doi:10.14627/537754020.

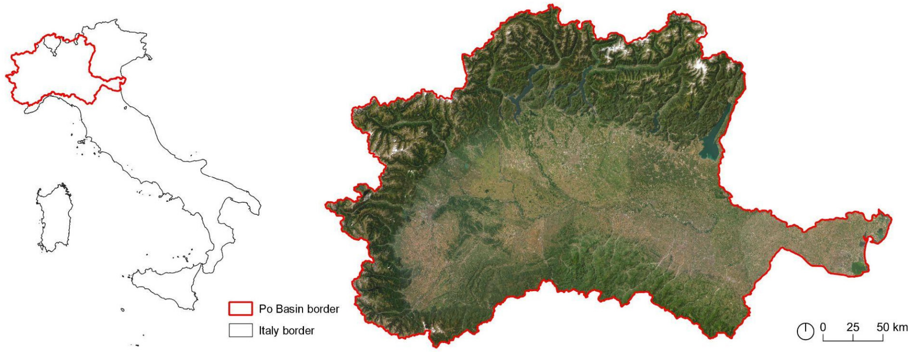

Fig. 1: Location of the case study: the Po Basin, in Northern Italy

2 Strategic Satellite Data and GIS Analysis Interpolation

The methodology of this study begins with acquiring open-source satellite data, organized into Thematic Layers that serve as the basis for analyzing the territory. The multiscalar nature of these observations enables the application of macro-scale strategies to micro-scale case studies, supporting strategic planning and ensuring comprehensive design control. Subsequently, all EO data are imported into a GIS environment and interpolated with detailed grids. This integration produces a comprehensive layer containing the necessary information to identify strategic areas for future territorial and landscape development. The methodology process is represented in Figure 2.

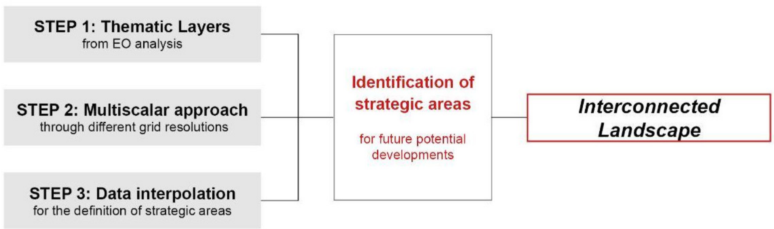

Fig. 2: Flowchart of the methodology work steps

2.1 Thematic Layers

The datasets employed in the present study demonstrate how the quality and health of territories can be effectively represented with the interpolation of various environmental features. To develop all the thematic layers that compose our multiscalar analysis approach, the Google Earth Engine (GEE) platform has been used, which, through its extensive Data Catalog provided us with several databases, easily callable and explorable through its Code Editor:

1) *Normalized Difference Vegetation Index (NDVI):* in this study, an NDVI analysis has been used to assess both the quantity and quality of vegetation in the areas of analysis and as a guide map to interrelate to the further data in the other thematic layers. To com-

pute the NDVI analysis for the region, ESA's Sentinel-2 satellite (S2) was used, which is a wide-swath, high-resolution, multispectral imaging mission with a global 5-day revisit frequency. Using its Multispectral Instrument (MSI), we accessed the Red and Near Infrared Reflectance bands, specifically b4 and b8, and carried out the following operation:

$$NDVI = \frac{NIR\ (b8) - RED\ (b4)}{NIR\ (b8) + RED\ (b4)}$$

The NDVI values for the study area, ranging from -1 to +1, were derived to produce a map representing the vegetation distribution. The utilized EO data was retrieved setting a time frame from 01 to 31/08/2024. The data were then filtered using the Copernicus CORINE Land Cover dataset to exclude urban areas. Subsequently, the filtered NDVI results were classified according to the system proposed by SABÓIA AQUINO (SABÓIA AQUINO & BESERRA OLIVEIRA 2012):

- -1 to 0 water bodies / built up;
- 0.0-0.2 very low vegetation cover (barren land);
- 0.2-0.4 low vegetation cover (shrubs and grasslands);
- 0.4-0.6 moderately low vegetation cover (sparse vegetation);
- 0.6-0.8 moderately high vegetation cover (medium vegetation);
- 0.8-1.0 very high vegetation cover (dense vegetation).

2) *Soil Water Content (SWC):* To estimate SWC, the "OpenLandMap Soil Water Content at 33kPa (Field Capacity)" dataset was used. This dataset provides volumetric soil water content (%) at 33kPa and 1500kPa suctions with a 250m resolution, covering the period from 1950 to 2017 in a single image. Training points for SWC predictions were derived from a global compilation of soil profiles (HENGL & GUPTA 2019).
3) *Soil Organic Carbon (SOC):* SOC estimation was conducted using the "OpenLandMap Soil Organic Carbon Content" database, which provides SOC data (5*g/kg) from 1950 to 2017 in a single image. This dataset offers a spatial resolution of 250m with an 8-day temporal frequency and is based on predictions from a global compilation of soil sampling points (HENGL & WHEELER 2018).
4) *Evapotranspiration (ET):* to assess the variability of evapotranspiration across the study area, the "Terra Moderate Resolution Imaging Spectroradiometer (MODIS) MOD16A2GF Version 6.1 Evapotranspiration/Latent Heat Flux (ET/LE)" dataset was used. This dataset provides a year-end gap-filled 8-day composite from 2000 to 2024, produced at a 500m pixel resolution, with values expressed in $kg/m^2/8$ days. The time frame of the data here utilized is from 01 to 31/08/2024.
5) *Urban Heat Islands (UHI):* to estimate the Surface Urban Heat Island effect, the procedure and classifications proposed by NAIM (NAIM & KAFY 2021) were used and utilized the GEE code provided by the authors and available on GitHub (AMIRHOSSEIN 2024). The analysis was conducted for July and August 2024, which are typically the hottest months in Italy. By accessing the ST_10 thermal band of Landsat 8 imagery in GEE and applying the code, we retrieved the land surface temperatures and calculated the average temperature for the study area. These values were then used to compute the Urban Thermal Field Variance Index (UTFVI), which is a key indicator for detecting and quantifying the Surface Urban Heat Island effect, using the following expression:

$$UTFVI = \frac{LST - LSTm}{LSTm}$$

In doing so, we obtained the UTFVI values for the area of study, which we then classified into 5 different categories:

- 0 to 0.005 weak thermal variance;
- 0.005 to 0.010 middle thermal variance;
- 0.010 to 0.015 strong thermal variance;
- 0.015 to 0.020 stronger thermal variance
- > 0.020 strongest thermal variance

6) *JRC Global Surface Water Mapping Layers v.1.4:* Given that our analysis is focused on the Po River Basin, it was crucial to identify and characterize all rivers and water bodies within the region. To achieve this, the Joint Research Centre's Water Mapping Layers v1.4 was utilized, which provides data on the occurrence of water bodies globally from 1984 to 2022. This dataset enabled us to observe both currently water-covered areas and those that have been inundated over the past decades.

All the data collected from the Po Basin are represented in Figure 3. Each map represents the specific minimum and maximum values of all the related datasets.

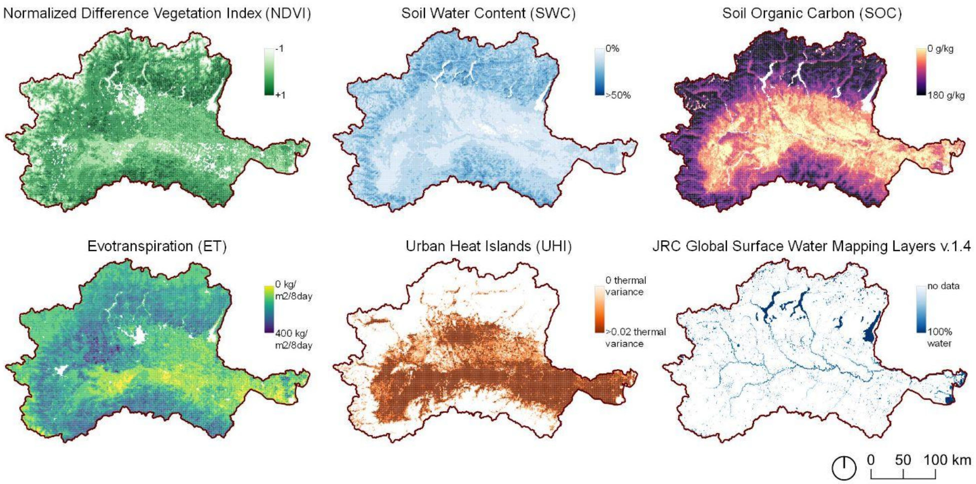

Fig. 3: Google Earth Engine (GEE) analyzes of the Po Basin

2.2 Multiscalar Approach

To highlight the potentiality of satellite data reading for their guidance and use in the framework of a multiscalar landscape and urban decision-making processes, we have decided to focus on two different scales which are:

- The Po River Basin, with an area of 74,011 km^2;
- Two focus areas of 375 km^2 each, which we selected by interpreting the data acquired on the first scale and which are better discussed in the results section.

These different extensions allowed us to adopt different scales of satellite data, with a definition of respectively 1*1km for the Po River Basin and 100*100m for the focus areas. Different satellite sensors provide data with various definitions. As an example, Sentinel-2 optical bands have a definition of 10m (EUROPEAN SPACE AGENCY n.d.), while Landsat 8 has a definition of 30m for the optical bands, and 100m for the thermal bands.

When exporting EO data from GEE to QGIS, all datasets were interpolated to match these scales, ensuring consistency across the different resolutions appropriate for both scales, territorial and focus, as shown in Figure 4.

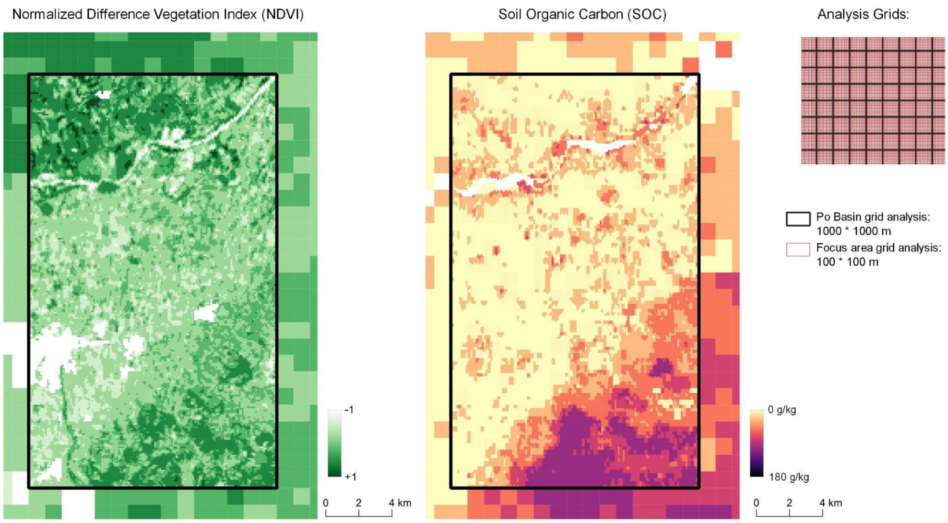

Fig. 4: Comparison of the two dataset resolutions for the Po Basin analysis and the Focus areas analysis

2.3 Data Interpolation

To utilize the analytical data for strategic and design purposes, the GEE data, in the form of georaster maps, was imported into a GIS environment, specifically the open-source software QGIS. The previously analyzed resolution was transformed into a regular geometric grid composed of square pixels with a 1*1 km step for the macro-scale analysis of the Po Basin case study, and a 100*100m step for the micro-scale analysis of the two design focus areas. Each GEE raster map and its corresponding datasets were interpolated with the geometric grid, obtaining the most common average value for each grid cell. When visualized collectively, this process produced a comprehensive initial analysis map. In addition to the interpolation of each previously described dataset, the grid was enriched with information on land use corresponding to each cell, providing a clear understanding of what each analysis and map represents. As a final result, two grids were obtained: one at the macro-scale and one at the micro-scale. Each cell within these grids contains all the intrinsic information related to that specific territorial portion. This data interpolation establishes the foundation for achieving a holistic view of all maps simultaneously, considering the territorial data under examination.

3 Results and Discussion

The outcome of the aforementioned landscape digitalization processes is the creation of a new synthetic map, enabling the identification of environmentally sensitive areas characterized by scarce conditions based on EO analyses, such as low vegetation cover, low Soil Organic Carbon, low Soil Water Content and significant Urban Heat Island variations. Within these, two focus regions, each covering 375 km², were selected to test the application of satellite data in guiding a sustainable landscape design approach and to evaluate its limitations. To obtain the map from the generated grid of 1*1 km, identify and select the focus areas, we set specific filters in QGIS, which are set with the following values: Soil Organic Carbon < 25 and Evapotranspiration value < 150 and Soil Water Content value < 32 and Urban Heat Islands value ≥ 3. These values are not scientifically rigorous thresholds universally recognized for each thematic map but empirically derived references that highlight areas with relatively lower values within each dataset, as represented previously in Figure 3. Conversely, the Urban Heat Islands value was set to identify areas with the highest thermal variance from the median land surface temperature in the Po Basin, emphasizing regions with increased thermal contrast. The results are shown in Figure 5.

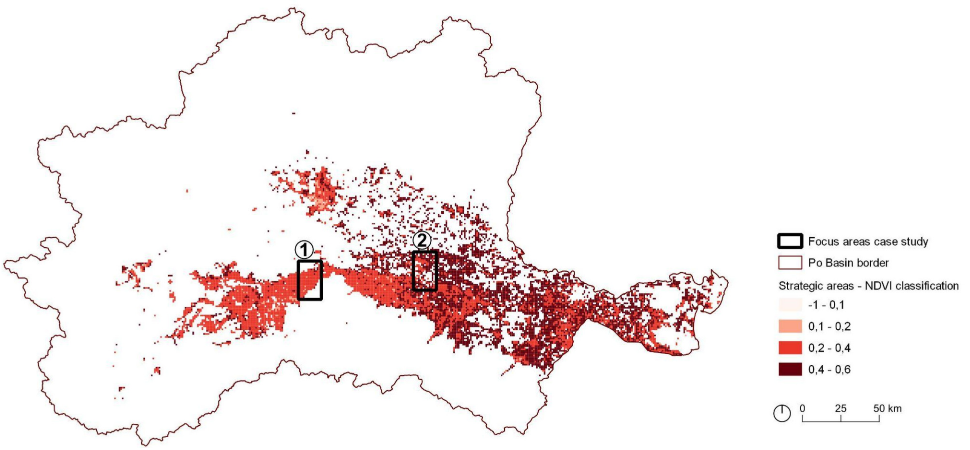

Fig. 5: Fragile and sensitive strategic areas for future potential developments at the Po Basin-scale and identification of the two focus areas

From these analyses, two focus areas were identified, and a smaller grid with a 100*100m resolution was created. While most datasets provided valuable insights at both scales, necessitating slight modifications to the Po Basin reference values, Urban Heat Islands data offered no additional value at the smaller scale and was excluded. The focus area grids were filtered using the following thresholds: Soil Organic Carbon < 12, Evapotranspiration < 98, and Soil Water Content < 30. Similar to the approach applied at the Po Basin scale, the lowest observed values for each dataset were used to select the most resource-deficient areas for each thematic map. These areas were identified as having significant transformative potential for strategic landscape interventions to enhance their intrinsic characteristics, as described below and represented in Figure 6:

- Focus Area 1: the hills and a segment of the Po River are fragmented by settlements and agricultural land. Contiguous medium to low-value parcels (pink and red pixels) could provide the base for the development of ecological corridors to restore connectivity between these ecosystems. Isolated parcels, instead, could be used for biodiversity hotspot enhancement and social services, such as forestation and new parks.
- Focus Area 2: centered around the city of Cremona, this area offers opportunities to strengthen ecological networks and urban connections between adjacent towns and the Po River. Proposed interventions could include enhancing river boundary interactions and forestation in isolated parcels where current agriculture might not be an optimal land use.

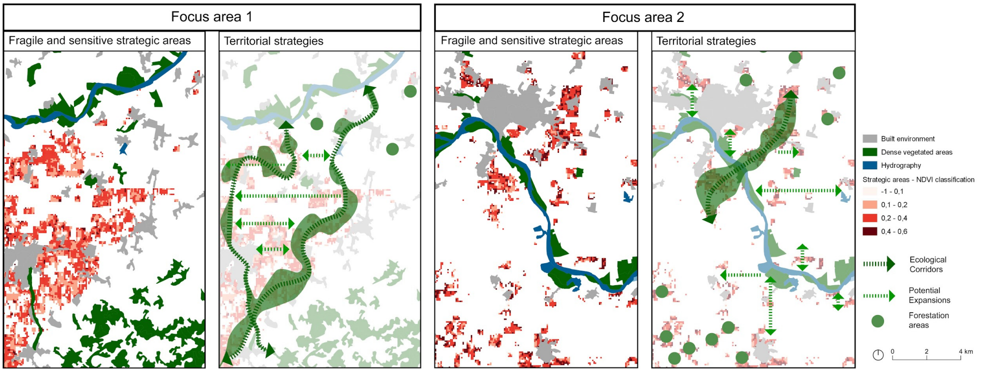

Fig. 6: Focus areas with the identification of potential landscape interventions for sustainable planning

Considering the two focus areas identified with the proposed methodology, this study lays the foundation for a sustainable approach to managing environmentally compromised areas and fostering their recovery. Such interventions support the development of new green infrastructure with ecological value while also enhancing the overall environmental quality and creating social development opportunities for local communities. By relying on concrete data and actual environmental conditions, municipalities and stakeholders responsible for territorial management can make more informed and sustainable decisions.

4 Conclusion and Outlook

This research highlights the potential of integrating open-source satellite data with multi-scalar analysis in Landscape Architecture. Earth Observation data provides valuable insights for decision-making, enhancing the ability to anticipate territorial assets within a coherent vision (LOBOSCO 2019) that supports environmental stewardship and sustainable projects. However, open-source datasets like Sentinel-2 (10m resolution) are suited for territorial planning but lack the detail needed for smaller-scale designs. Higher-resolution imagery (up to 0.15m) is costly and typically covers large areas (PLANETEK ITALIA 2024). Rather than a limitation, this could be an opportunity for municipalities to share costs and implement sustainability standards across various scales. Integrating EO tools with GIS could enhance spatial analysis and planning across different scales of interventions. Moreover, as Artificial Intelligence (AI) and Machine Learning (ML) become more accessible, they could further simplify the process, making advanced environmental assessments more intuitive and widely available to architects, engineers and planners.

References

AMIRHOSSEIN, A. (2024), Landsat UHI (Google Earth Engine), Github. https://github.com/amirhosseinahrari/googleearthengine/blob/26665c875d9ec4c187bb505db31ded3bc7133781/00035_landsat_uhi (23.12.2024).

EUROPEAN SPACE AGENCY (n. d.), Sentinel-2: Colour Vision for Copernicus. https://www.esa.int/applications/observing_the_earth/copernicus/sentinel-2 (07.01.2025).

HENGL, T. & WHEELER, I. (2018), Soil Organic Carbon Content in x 5 g / kg at 6 Standard Depths (0, 10, 30, 60, 100 and 200 cm) at 250 m Resolution'. Zenodo. https://doi.org/10.5281/zenodo.2525553.

HENGL, T. & GUPTA, S. (2019), Soil Water Content (volumetric %) for 33kpa and 1500kpa Suctions Predicted at 6 Standard Depths (0, 10, 30, 60, 100 and 200 cm) at 250 m Resolution. Zenodo. doi.org/10.5281/zenodo.2784001.

LESER, H., NAGEL, P. (2001), Landscape diversity – a holistic approach. In: BARTHLOTT, W., WINIGER, M. & BIEDINGER, N. (Eds), Biodiversity. Springer, Berlin/Heidelberg. https://doi.org/10.1007/978-3-662-06071-1_9.

LOBOSCO, G. (2019), Il paradosso dei paesaggi disturbati dalla transizione energetica. L'isola di Pantelleria verso nuovi ecosistemi. Ri-Vista. Research for Landscape Architecture, 17(2), 176-191. https://doi.org/10.13128/rv-8324.

LOBOSCO, G., TINTI, L. & MAGAGNOLI, B. (2023), Landscapes of drought. Future scenarios between agriculture and land aptitudes. Ri-Vista. Research for Landscape Architecture, 21(1), 218–237. https://doi.org/10.36253/rv-14112.

MCHARG, I. L. (1969), Design with Nature. John Wiley & Sons Inc., Hoboken.

NAIM, M. D. N. H. & KAFY, A. A. (2021), Assessment of Urban Thermal Field Variance Index and Defining the Relationship Between Land Cover and Surface Temperature in Chattogram City: a Remote Sensing and Statistical Approach, Environmental Challenges, 4, 100-107. doi.org/10.1016/j.envc.2021.100107.

PLANETEK ITALIA (2024), Conversation with the Sealine Research Centre.

SABÓIA AQUINO, C. M. & BESERRA OLIVEIRA, J. G. (2012), Estudo da Dinâmica do Indice de Vegetacão por Diferença Normalizada (NDVI) no Nucleo de São Raimundo Nonato-pi, GEOUSP: Espaço e Tempo, 16(2), 157-168. doi.org/10.11606/issn.2179-0892.geousp.2012.74261.

VON HUMBOLDT, A. (2018), Quadri della natura. Codice Edizioni, Torino.