Hiking in Appennino Tosco-Emiliano: an Elevation & Visibility Analysis

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***Abstract*—This study analyzes the topography, hiking trails, and intervisibility within the Appennino Tosco-Emiliano National Park using GIS techniques. Key findings include the identification of the most panoramic trails and detailed elevation profiles, enhancing our understanding of the hiking landscape. The intervisibility analysis reveals significant visual connectivity between trails and peaks. This integrated approach provides a framework for optimizing hiking experiences and preserving the park's scenic and ecological values.**

Keywords: intervisibility, mountain peaks, hiking trails, GIS, landscape analysis, elevation.

I. Introduction

The Appennino Tosco-Emiliano National Park, with its diverse topography and rich natural landscapes, offers an array of hiking opportunities that attract outdoor enthusiasts and nature lovers. This study focuses on the intricate relationships between the terrain, hiking trails, and viewpoints in Appennino Tosco-Emiliano.

In this paper, we present a comprehensive elevation and visibility analysis, utilizing data from various sources. By integrating geographic information system (GIS) techniques, we aim to provide insights into the terrain's characteristics and visual connectivity between mountain peaks and hiking trails within the area.

The following sections detail our approach: beginning with an overview of the data sources and preprocessing steps, we then delve into the exploration of a Digital Elevation Model (DEM) and mountain peaks data, examining elevation discrepancies and the structure of the hiking trails network. Subsequently, we conduct a rigorous intervisibility analysis to identify panoramic trails and significant viewpoints, culminating in the establishment of a full intervisibility network that highlights the visual interactions between prominent peaks and trails.

A. Study Area

The region chosen for this study is the **Appennino Tosco-Emiliano** National Park [1] (Fig. 1), a state-held natural preserve in Northern and central Italy. The National Park was founded in 2001, and is included in the provinces of Massa-Carrara, Lucca, Reggio Emilia and Parma with an extent of 227.92 km^2. This area has notable biodiversity, with 16 different habitats, 20 protected wildlife species and 4 protected flora species [2]. The territories of Appennino Tosco-Emiliano develop from the main ridge of the Apennines to its surrounding hills and are characterized by a great variety of exposure and altitudes generating different environments: from the coldest and barest ones to forests and hills.

In order to include the territory surrounding the National Park, the area of interest of this study consists of a 55x40km region centered around Appennino Tosco-Emiliano, defined in EPGS:4326 coordinates *(9.899299, 44.166271, 10.601051, 44.527670).*

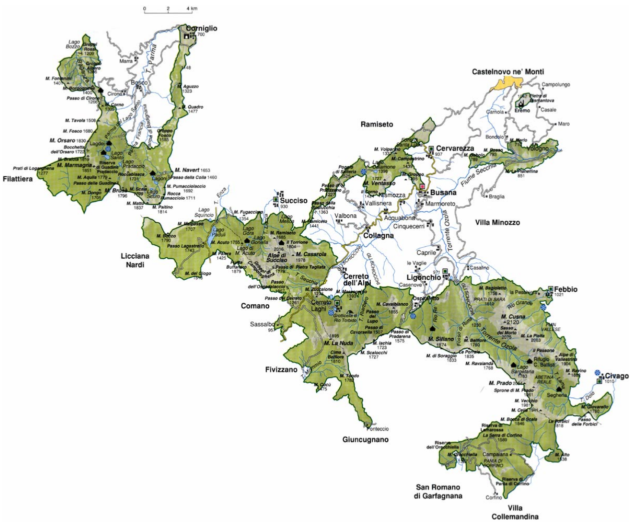

Fig. 1: Appennino Tosco-Emiliano [1]

II. Data

This study comprises a variety of data sources and formats, which needed to be preprocessed before proceeding with the analysis. The data consisted of a Digital Elevation Model (DEM) and several datasets: the mountain peaks, the network of hiking trails, and the viewpoints.

A. Data Sources

First, the **Digital Elevation Model (DEM)** was retrieved using the Tinitaly *WCS* (Web Coverage Service) endpoint provided by Istituto Nazionale di Geofisica e Vulcanologia (INGV), published with a CC BY 4.0 license [3]. Unlike a WMS and a WMTS, which return spatial data as static maps, the WCS makes available spatial data with their attributes that can be interpreted, analyzed and processed. The Digital Elevation Model was downloaded in geoTIFF format with a resolution of 10m, which is the original resolution provided by Tinitaly.

The bounding box used to narrow the request to the study area has been created with the online tool *bbox finder* [4], which operates in EPSG:4326. To retrieve the DEM, this box has been converted in EPSG:32632 - UTM zone

32N. The main difference between these CRS is the unit, the first being in degrees and the latter in meters. For the purpose of analysis, the CRS chosen for the project was **EPSG:32632 - UTM zone 32N**.

Secondly, **mountain peaks** data was downloaded from OpenStreetMap (OSM) [5] querying the *Overpass API* [6]. The data is available with the ODbL[1] license. In OSM, mountain peaks can be downloaded as points using the *"natural"="peak"* tag. The same bounding box was used to download the data and save it in geoJSON format.

Lastly, the *WFS* (Web Feature Service) endpoint from Regione Emilia-Romagna [7] provided data about the hiking trails network. This geoportal has a CC-BY license and offers a wide variety of information about the hiking network of the entire region, such as parking spots, huts, camping sites, water points, etc. Among these, there are layers about **hiking trails** (represented as Linestrings and Multilinestrings) and **panoramic viewpoints**. They have been downloaded with two separate requests and saved in distinct geoJSON files. The viewpoints request consisted of the combination of five different layers based on the orientation of the viewpoints.

B. Data Preprocessing

In order to be consistent and ready for the analysis, the downloaded data underwent some preprocessing. This is a fundamental step, given the different data sources, geometry types and file formats. The aim was mainly to ensure all datasets shared the same CRS and bounds, as well as accounting for missing values.

The DEM did not require any preprocessing, since it was downloaded using the bounding box of the study area and in the project's CRS. Moreover, it did not contain missing values. Therefore, the rest of the data had to be adjusted accordingly.

The mountain peaks geodataframe was also downloaded within the bounding box, but underwent some preprocessing: first it was reprojected to the project's CRS (EPSG:32632 - UTM zone 32N); secondly, the elevation column *ele* was formatted as numerical; third, the presence of NaNs was assessed for the *name* and *ele* columns. The *name* NaNs were substituted with the value in the *alt_name* column, if present, else they were removed; the *ele* Nans were filled with the corresponding elevation value contained in the DEM, also reported for all records in a new column in the dataset. Further, the peaks whose coordinates fell on the bounds of the DEM were dropped, as well as peaks with an elevation below 600m. The dataset initially contained 558 records and was reduced to 493 after preprocessing.

For practical reasons, the hiking trails and viewpoints have been downloaded without the bounding box[2], thus after being reprojected in the correct CRS (from EPSG:4326) they were clipped on the study area. The columns of both geodataframes were inspected for NaNs: none were found.

[1] Open Data Commons Open Database License.

[2] So for the entire Emilia-Romagna region.

III. Methodology

This study has been conducted using two different frameworks.

Data download and preprocessing was performed in **Python** through the use of several libraries, using two *Jupyter Notebooks*. Data exploration and graph analysis were also carried out in the same scripts.

The intervisibility analysis was performed in **QGIS** using the Visibility Analysis plug-in [8]. The reason behind this choice was mainly due to the computational cost of such analysis, which can quickly scale up for large networks: a purpose-specific GIS software such as QGIS proved to be effective. Data layers for this part of analysis were already preprocessed in the previous analysis in Python, ready to be simply imported in QGIS without the need to perform any additional preprocessing.

IV. Data Exploration

A. DEM & Mountain Peaks

We begin by exploring the Digital Elevation Model (DEM) to understand the terrain's characteristics within our area of interest. The DEM provides a 3D representation of the terrain's surface, offering valuable insights into elevation patterns, slope, and topographical features. This exploration forms the foundation for understanding the spatial distribution of the terrain. The Tinitaly DEM contains one single band from which the elevation data can be read as an array.

The average elevation is around 815m, while the minimum registers at 26m and the maximum at roughly 2120m. This already highlights the variability of the terrain in Appennino Tosco-Emiliano and the fact that it is a mountainous area between two flatter regions: the Padan Plain and Tuscany. As represented by the contour lines in Fig. 3, there is a gradual increase of elevation, starting from lowland, encompassing hills and ending in the evident Apennines alpine strip where maximum elevation is reached. *Altimetric areas* have been computed: lowland (below 300m) makes up only 9.4% of the area, hills 22.4% and the remaining 68.2% is mountainous area (Fig. 3).

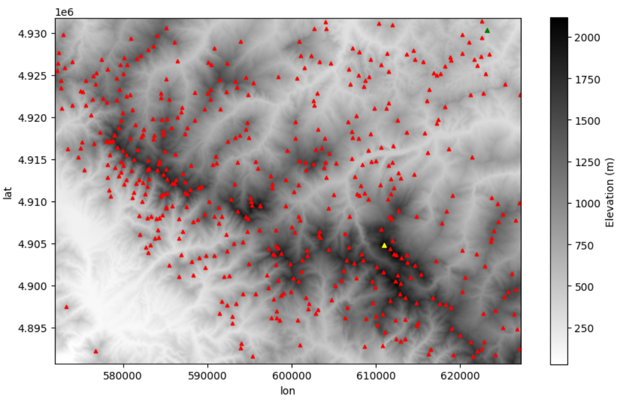

Fig. 2: Elevation & mountain peaks. The highest peak is Monte Cusna (yellow); the lowest peak is Poggio Tassinara (green).

This information can be further enriched by exploring the mountain peaks data. The average peak elevation is

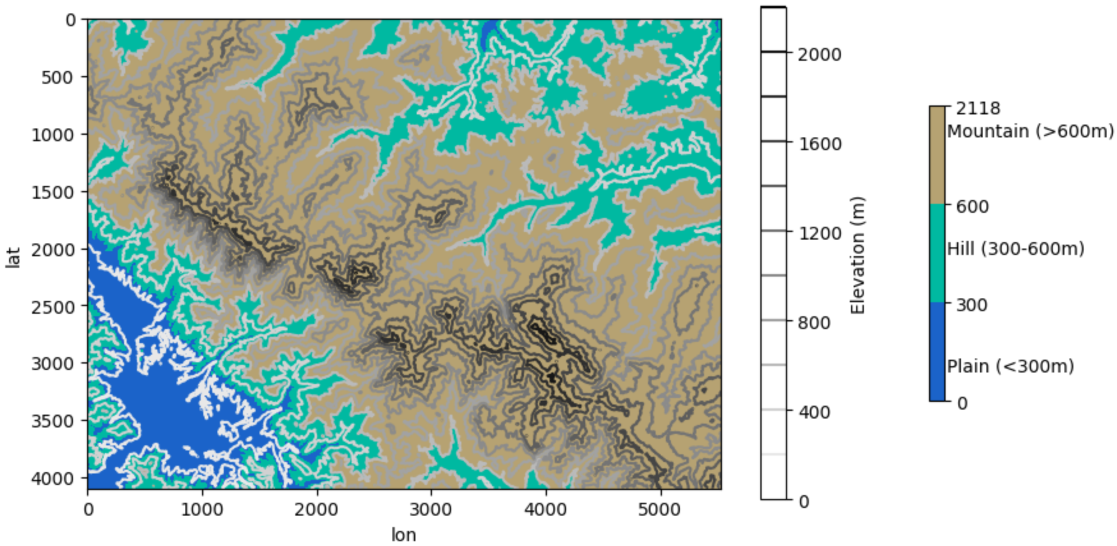

Fig. 3: Altimetric areas & contour lines.

1213.76 m; the highest peak is Monte Cusna (2120.0 m) and the lowest peak is Poggio Tassinara (607.0 m). Out of the 493 peaks, most are within the elevation range 1000-2000m. Only 6 peaks are above 2000m: Alpe di Succiso, Sasso del Morto, Monte La Piella, Antecima Est Monte La Piella, Monte Cusna and Monte Prado.

B. Elevation Differences Between DEM and OSM

Particular attention was given to comparing the elevation data provided by the Digital Elevation Model and the elevation associated to each peak in OSM. This has been achieved by extracting the elevation from the DEM using the point coordinates of each peak and storing this information in a new column in the peaks' geodataframe named *ele_dem*. Then, another column *ele_diff* was created to store the difference between the two elevations for each peak. The mean difference is of 11m, with a standard deviation of 24m. From the figures (Fig. 10, 11) it emerges that the DEM tends to report a slightly lower elevation than OSM data. Not surprisingly, this difference changes with respect to the resolution used in the DEM, as reported in Table I.

Resolution	Mean	Std. Dev
10 m	11m	24m
100 m	45m	36m

TABLE I: Statistical differences in elevation with different resolutions.

In the projects' resolution (10m) this difference was not considered significant, meaning that both sources may be considered valid. However, it is an important matter to address before choosing which one to consider for analysis. This choice also depends on the type of analysis conducted: in our case, elevation data is used to build an intervisibility network and viewshed maps, therefore the Digital Elevation Model was the chosen data source for elevation, while the mountain peaks geodataframe provides the locations of the peaks.

C. Hiking Trails Network

The hiking trails data consists of 347 trails represented as Multilinestring and Linestring geometries. A Multilinestring is a collection of Linestrings, determined by various points-pairs between a start-point and end-point. Each trail is named with a number, and here also identified with a few different IDs, as well as information on the location of the trail. Other useful information provided is the type of trail sign, length, and difference in altitude. The average trail length is 5.45km and the average elevation gain is +420.28m. There are also challenging itineraries: the longest trail is 00 (Passo Dei Due Santi - Poggio Delle Ignude, 89.64km), which is also the trail with the maximum elevation gain (+7982.30m) (Fig. 4). The trail with maximum slope (64.02%) is 120: a short path (140m) on Passo delle Guadine (1589.7m above sea level).

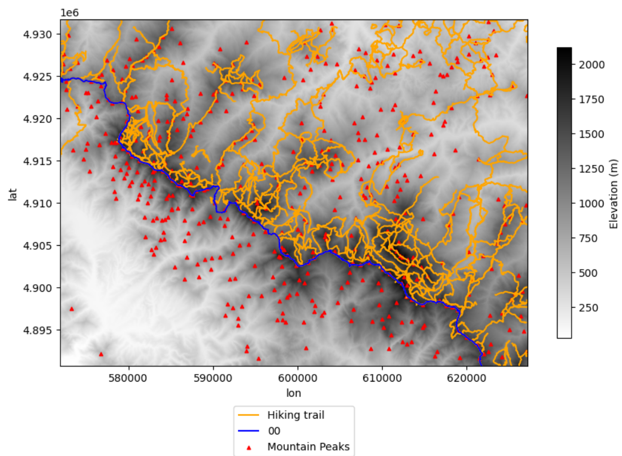

Fig. 4: Hiking trails network. Trail 00 in purple.

The trail network may be represented as a **graph**, where each trail consists of a sequence of nodes connected by edges. The resulting graph is quite *dense*, with 81170 nodes, 81462 edges and 81023 intersections. The graph structure may be exploited to identify the point of the national park with the most **trail intersections**, i.e. the node with the highest *degree*. One thing to take into account is the fact that nodes that are not "extremes" (start or end points) of a trail will have a degree *D* that does not directly correspond to the number of distinct trails intersecting in that node[3]. Due to this, and to have a broader focus, the main intersection points have been identified as those with maximum degree *D=6* or the previous value (*D=5*). Figure 5 shows the location of the main intersection points and connected trails: not surprisingly, all three are located on mountain passes between Emilia-Romagna and Tuscany.

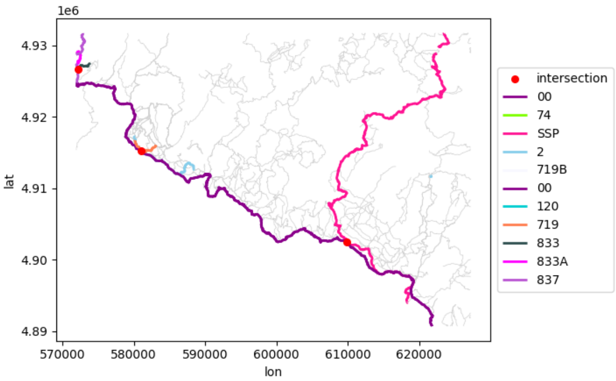

Fig. 5: Main intersection points.

D. Viewpoints & Panoramic Trails

The viewpoints' data can provide further insights. There are 58 viewpoints marked in the study area, classified by orientation (Fig. 12). Most viewpoints face South or East. This data layer has been used to identify the most panoramic trail, defined as the trail with highest number of viewpoints. For each trail, a spatial inner join between the trail geometry and the viewpoints geodataframe was performed, returning only the viewpoints on the trail (with a 50m buffer); the length of the resulting geodataframe was then saved in a new column in the trail geodataframe, allowing to identify the trails with highest number of viewpoints. The most **panoramic trails** are:

- SSP (Sentiero Spallanzani)
- 763 (Moragnano - Pieve di Sasso)

with 6 viewpoints each.

A comparison of the two trails was carried out focusing on terrain characteristics such as elevation and slope, to create a more complete characterization of such paths. Once again, this analysis was carried out using graph representations of the two trails. SSP is roughly 80km long[4], starting from the city of Reggio Emilia and reaching the highest peaks of Appennino Tosco-Emiliano at around 1800m, with an overall altitude difference of 5000m [9]. From now on, when referring to SSP we will only consider the section of the trail within the area of interest of the study. On the other hand, trail 763 is a 7km hike in the province of Parma. They are already quite different itineraries. This difference is also observable in the **elevation profiles** (Fig. 6, 7). Note that these have been produced only for one way (start to end), not for the entire roundtrip. SSP starts at about 500m above sea level and reaches a maximum altitude of 1800m, to then slightly decrease at the trail-end around 1500m. It is an overall gradual ascent, but there are also many downhill sections. This elevation profile reflects the long-distance character of the itinerary, passing through different terrains and requiring multiple days to be completed: by looking at the elevation profile, it is clear that at about two thirds of the trail (around km50) the hills are left behind to enter a more alpine environment. The elevation profile for 763 is more typical of a single-day hike: the elevation increases – and decreases – in a more constant manner. This trail is shorter and thus has a reduced elevation range (700m-1100m).

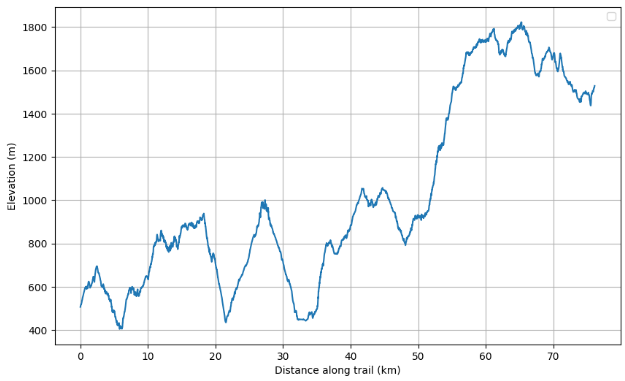

Fig. 6: Elevation profile for trail SSP.

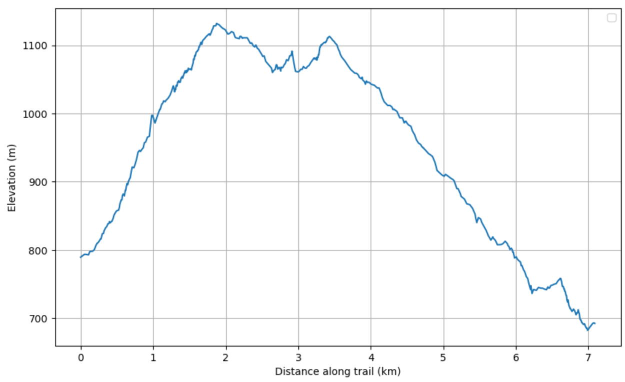

Fig. 7: Elevation profile for trail 763.

Another important aspect to consider is the **slope**, that is the ratio of elevation change to horizontal distance (the angle of inclination of the ground surface). Slope analysis provides useful insights on difficulty of a trail and identifying challenging sections. Due to the dense nature of these graphs[5], instead of computing the slope for each edge, the trails were divided into 1km segments and the average slope was computed for each segment. Obtained values were then categorized into four groups: *downhill* (negative slope), *flat* (below 5%), *moderate* (below 15%) and *steep* (above 15%) (Table II).

Similarly to elevation, the slope has been computed only for one way, traversing the graph from the start to end

[3]Non-extreme nodes have two edges from the same trail connected.

[4]125km in total if the lowland section outside the study area is considered.

[5]Mean edge length: 18.6m (SSP) and 15.3m (763)

points. Thus, walking the trail in the other direction will result in opposite slope categories. By looking at Figures 13, 14 it is possible to get a better grasp on the slope of the trail as it progresses, which may be useful for planning to hike it.

Trail	Downhill	Flat	Moderate	Steep
SSP	29	20	21	8
763	5	1	0	2

TABLE II: Slope categories.

V. Intervisibility Analysis

Intervisibility analysis is a crucial aspect of evaluating the visual connectivity between mountain peaks and hiking trails. By determining which peaks are visible from the trails and other mountains, this analysis helps in understanding the visual landscape and enhancing the hiking experience. As stated in the Methodology, this part of analysis was carried out in QGIS using the Visibility Analysis plug-in. Detailed commands to reproduce the analysis are available in the project's repository. Several **intervisibility networks** have been computed using the following workflow:

1) Create a set of *observer points*[6] using the *Create observer points* module;
2) Feed DEM, observer and target points to the analysis modules (e.g. *Intervisibility Network*).

The result is a network, in vector format, of visual relationships – links – between two sets of points (or within a single set). For each link the *depth below/above visible horizon*[7] is calculated, as in many cases only a portion of the specified target is visible. The following intervisibility networks have been computed using an *analysis radius* of 20km and *observer height* of 1.70m to simulate an average adult observer.

A. Panoramic Trails: Visible Peaks

Carrying on with the comparison of the most panoramic trails (SSP and 763), two intervisibility networks were generated to understand which mountain peaks are visible from the viewpoints of each trail. Following the workflow described above, for each trail, the viewpoints layers were used as *observer points* and the mountain peaks layer provided the *target points*.

There are 131 mountain peaks visible from the viewpoints on SSP trail (Fig. 15). Viewpoints 0 and 1 are along the crest of Cima La Nuda, at an altitude of about 1630m, and together look at 60 mountain peaks mostly towards North. Viewpoint 3 (1000m) is located on the NW side of the summit of Pietra di Bismantova, looking at 43 peaks. Lastly, 28 peaks are visible from the viewpoints with lowest elevation (4, 5) at around 775m, in the SW direction. Particular attention was devoted to viewpoint 2, which in the resulting network is not linked to any peak. To further investigate this, a **binary viewshed** for this point was computed. It consists of a visibility map where each data point of a terrain model is assigned a true/false value (visible/not visible). The resulting viewshed map (Fig. 18) is in line with the lack of visible peaks in the intervisibility network: this point has a very restricted field of vision without any peak, although some are very close, suggesting they may be only partially visible. Moreover, if we consider the elevation of this point and of the near-by terrain, it appears to be in a narrow valley between two higher crests: viewpoint 2 is located at 1226m, between Monte Cusna (2120m), Monte Sillano (1867m) and their descending slopes. This explains the lack of visible peaks. The fact that it is still marked as a viewpoint is likely not due to coordinate inaccuracy, but perhaps refers to the steep and narrow landscape with partially visible peaks: in fact, after this point the trail becomes increasingly steeper and reaches an altitude of 1700m. Overall, the intervisibility network for Sentiero Spallanzani (SSP) highlights the fact that it offers several viewpoints at different elevations, covering all directions and therefore making it a valid option for a multi-day hike to explore the Eastern side of Appennino Tosco-Emiliano.

Regarding the mountain peaks visible from the viewpoints on trail 763 (Fig. 16), there is a total of 63 visible peaks, almost half of which are visible from viewpoint 5 (28 peaks towards SE). Interestingly, it is the viewpoint on trail with the lowest elevation (816m), compared to the other which are all between 1000-1100m. Viewpoints 0,1,2 look at mountains to the West such as Monte Caio (1580m), Monte Barcone (1400m) and Monte Polo (1415m). The mountains in this area are generally lower. Similarly to viewpoint 2 in trail SSP, here viewpoint 3 did not have any link in the visibility network. This lack of visibility emerges also from the binary viewshed produced for this point (Fig. 19).

The intervisibility networks for each trail are vector layers that can be *intersected* to find out which mountain peaks are **visible from both trails** (Fig. 8). 17 mountains are visible from both SSP and 763, respectively from viewpoint 3 on SSP and viewpoint 5 on 763. The highest visible peak in common is Monte Ventasso (1720m).

B. Pietra di Bismantova: Visible Peaks

We have already mentioned Pietra di Bismantova, since it is one of the viewpoints of Sentiero Spallanzani. This mountain is a geological formation (*monadnock*[8]) with the shape of a narrow, quasi-cylindrical plateau (measuring 1 km x 240 m) whose steep walls emerge 300 meters as an isolated spur from the nearby hills [10]. Other than SSP, there are two other trails reaching the top: 699 and 697 (including variations like 697A). The summit plateau (1040m above sea level) can be walked all around and its peculiar structure emerging from the gentle hills of the lower Apennines make this an excellent panoramic viewpoint, with a 360° view on Appennino Tosco-Emiliano.

[6] Same procedure applies for target points.

[7] Depth at which lay invisible portions of a terrain. This value can be understood as the theoretical height a peak should attain in order to appear on the horizon, as visible from the chosen observer point.

[8] An isolated small mountain that rises abruptly from a gently sloping or virtually level surrounding plain.

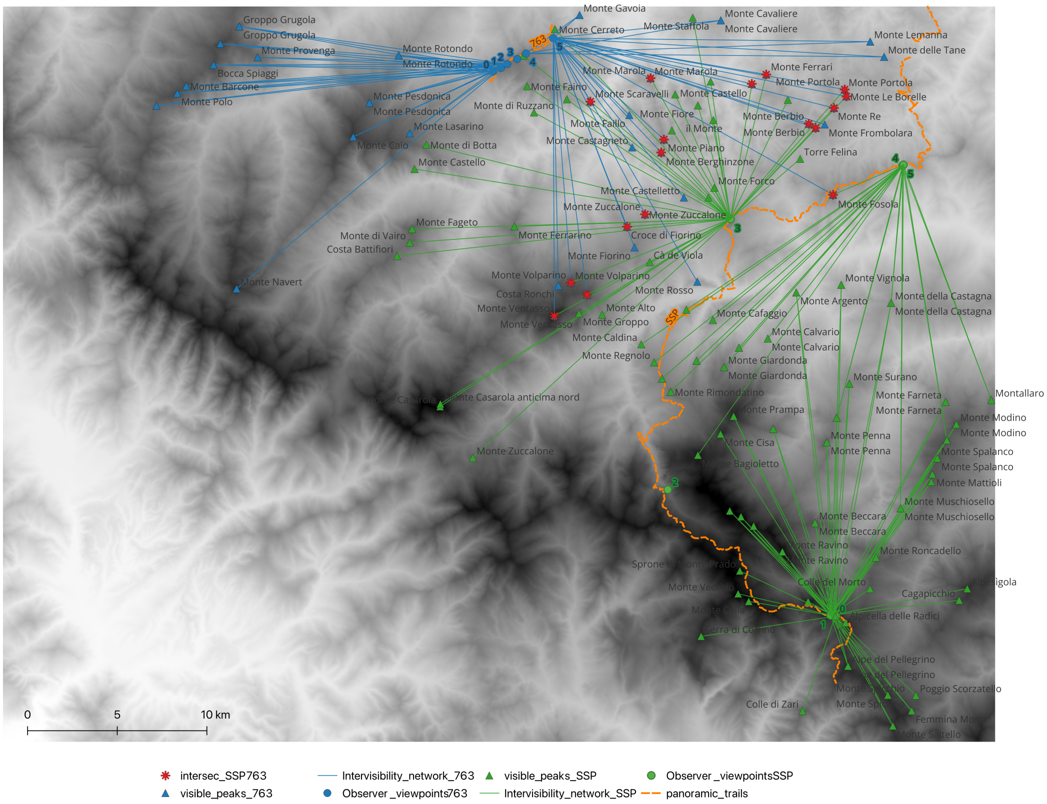

Fig. 8: Mountain peaks visible from both panoramic trails (red star).

The visibility network (Fig. 9) was created by merging the visibility network for viewpoint 3 of trail SSP and the visibility network created using the peak of this mountain from OSM. These points are indeed located on two opposite sides of the summit: the SSP viewpoint faces NE, while the OSM peak-point faces SW. There are 84 visible peaks, including Monte Fuso and Monte Cerreto which are also on trail 763.

C. Full Intervisibility Network

Following the same logic, it is possible to compute an intervisibility network using the peaks' layer as both *observer* and *target* points. This produces a dense network that includes all intervisibility relationships between mountains. Rather than visualizing the entire network at once, which may not be so informative, it may be filtered to answer specific questions. For instance, one can focus on the **peaks above 2000m**: by setting them as observers it is possible to compute which peaks are visible from them (N_{out}). Oppositely, one can check from how many mountains these are visible (N_{in}). The results are visible in Fig. 17 and Table III.

For most of the highest mountains, the number of observable peaks and the number of peaks from which they are visible do not always coincide. Alpe di Succiso, Monte La Piella and its pre-summit[9] are visible from less peaks compared to how many are observable from their summits.

[9] Antecima Est Monte La Piella.

name	N_{out}	N_{in}
Alpe di Succiso	114	100
Sasso del Morto	33	36
Monte La Piella	147	86
Antecima Est Monte La Piella	76	39
Monte Cusna	48	51
Monte Prado	59	59

TABLE III: Peaks above 2000m.

On the other hand, Monte Cusna and Sasso del Morto can be observed from 3 additional peaks that are not visible from them.

VI. Conclusions

This study has provided an in-depth analysis of the elevation and visibility characteristics of the Appennino Tosco-Emiliano National Park, emphasizing the intricate relationships between the terrain, hiking trails, and viewpoints. Through the integration of Digital Elevation Model (DEM), OpenStreetMap (OSM) data, and regional geospatial datasets, we have created a comprehensive understanding of the topography and visual connectivity within the park. The key conclusions drawn from this research are as follows:

1) **Terrain Variability**: The Appennino Tosco-Emiliano region exhibits significant elevation variability, with altitudes ranging from 26 meters to 2120 meters. This diverse topography supports a wide range of habitats and offers a rich variety of hiking experiences. The analysis revealed

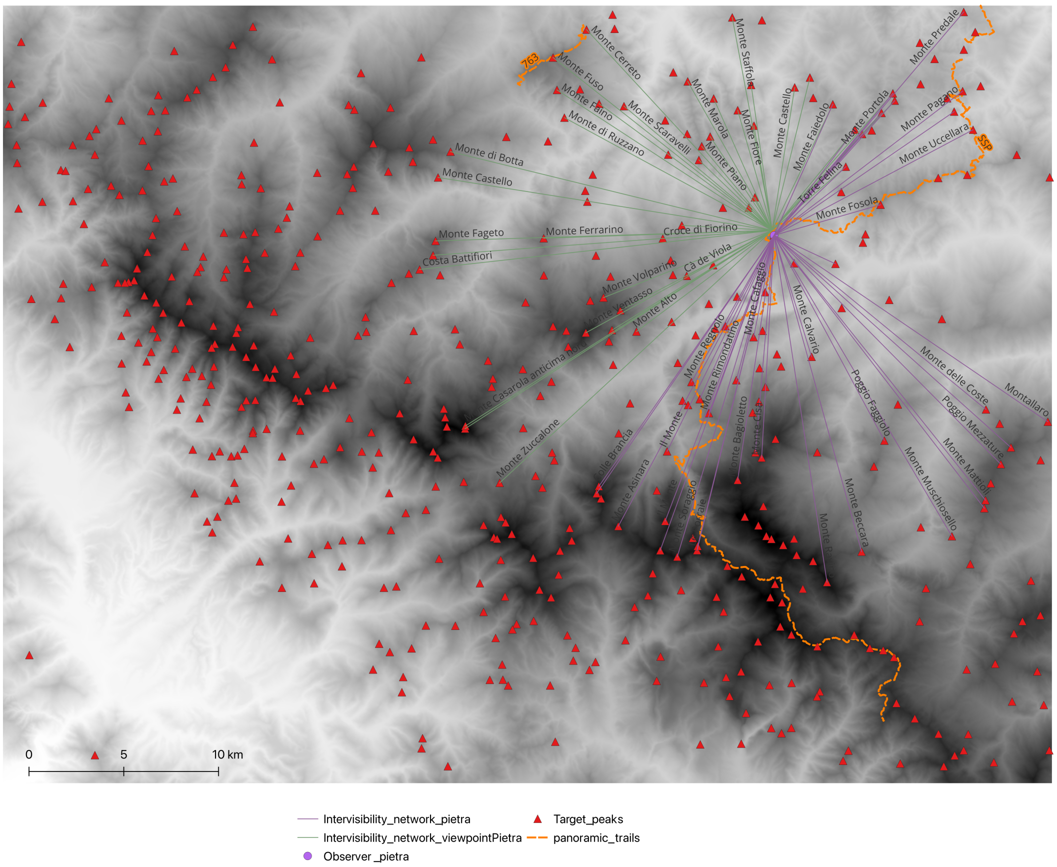

Fig. 9: Intervisibility network from Pietra di Bismantova. Green lines indicate peaks visible from the NW side; violet lines represent peaks visible from the SE side.

that a large portion of the area is mountainous (68.2%), which highlights the region's suitability for extensive and challenging hiking trails.

2) **Hiking Trails Network**: The hiking trails network is extensive and well-distributed across the park, with trail 00 (Passo Dei Due Santi - Poggio Delle Ignude) being the longest and most challenging in terms of elevation gain. The analysis of trail intersections identified key points where multiple trails converge, providing valuable information for hikers planning multi-trail itineraries.
3) **Panoramic Viewpoints**: The identification of panoramic trails and significant viewpoints was achieved through spatial analysis and intervisibility networks. Trails SSP (Sentiero Spallanzani) and 763 (Moragnano - Pieve di Sasso) were highlighted as the most panoramic, each offering unique visual experiences. SSP provides a broad range of elevations and directions for viewing, while 763 offers a more localized but still impressive set of vistas.
4) **Intervisibility Analysis**: The intervisibility networks established clear visual connections between numerous mountain peaks and hiking trails. This analysis enhances our understanding of the visual landscape and helps in identifying trails that offer the most scenic views. The intervisibility network from Pietra di Bismantova, for instance, shows how specific viewpoints can offer extensive visibility over multiple peaks, contributing to the region's allure for hikers.

The insights gained from this study are valuable for trail management, tourism planning, and conservation efforts within the Appennino Tosco-Emiliano National Park. By understanding the visual and topographical characteristics of the area, park authorities can better design and maintain trails, enhance visitor experiences, and ensure the protection of the park's natural beauty. Overall, this research underscores the importance of integrating advanced geospatial techniques in the study of natural landscapes.

VII. Code Availability

Code to reproduce results is available at https://github.com/sraatgn/mountainpeaks-intervisibility.

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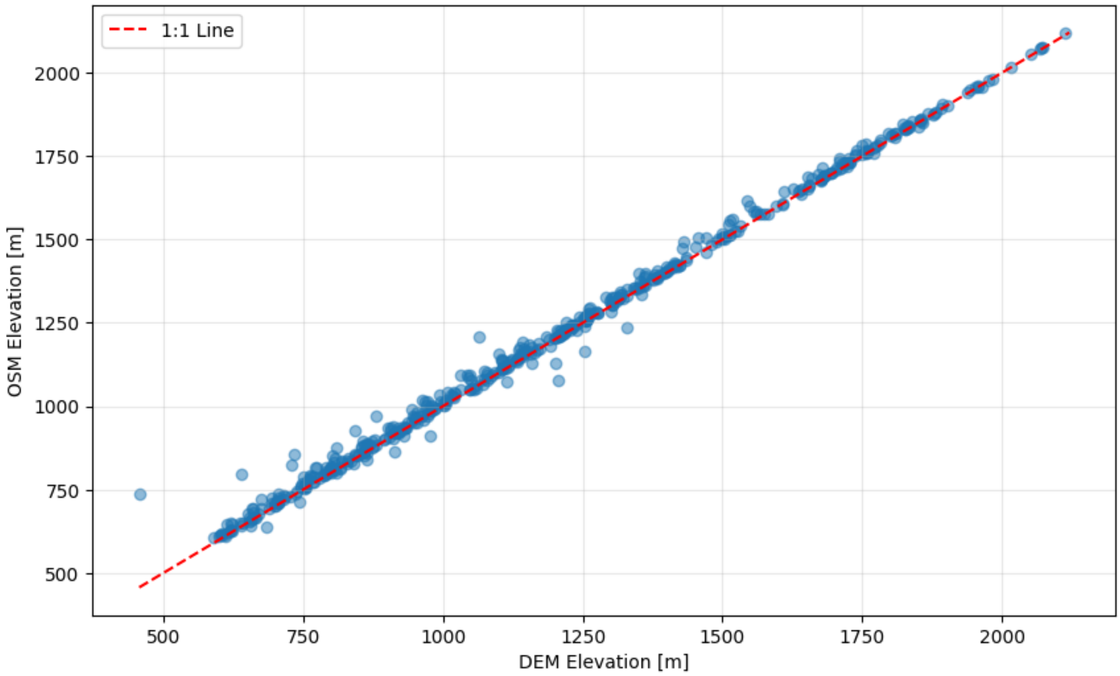

Fig. 10: DEM & OSM elevation difference line plot. The closer a point is to the red line, the smaller the difference between the elevation value reported in the DEM and OSM.

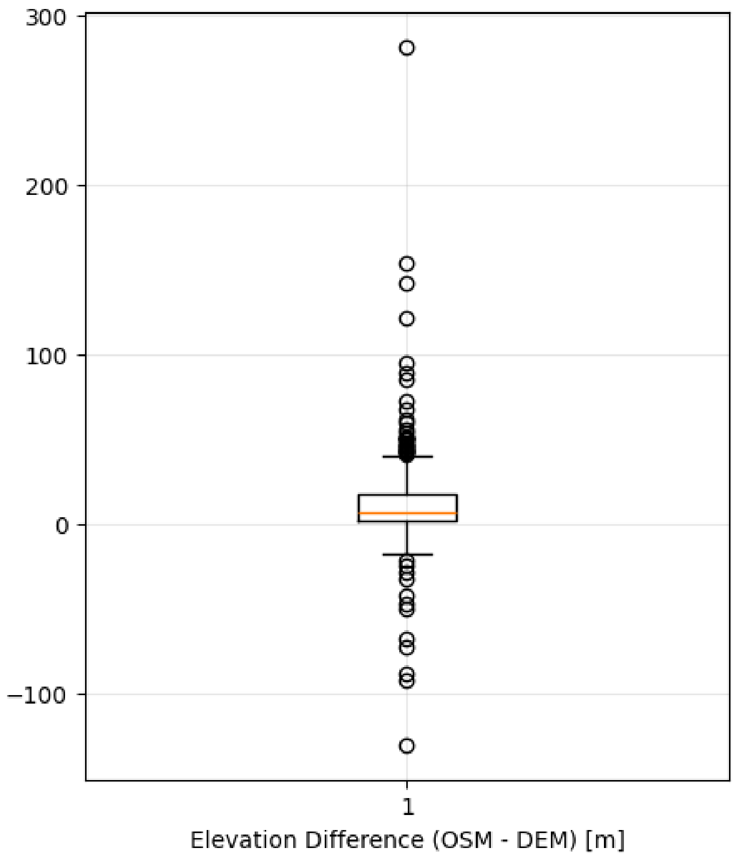

Fig. 11: DEM & OSM elevation difference boxplot.

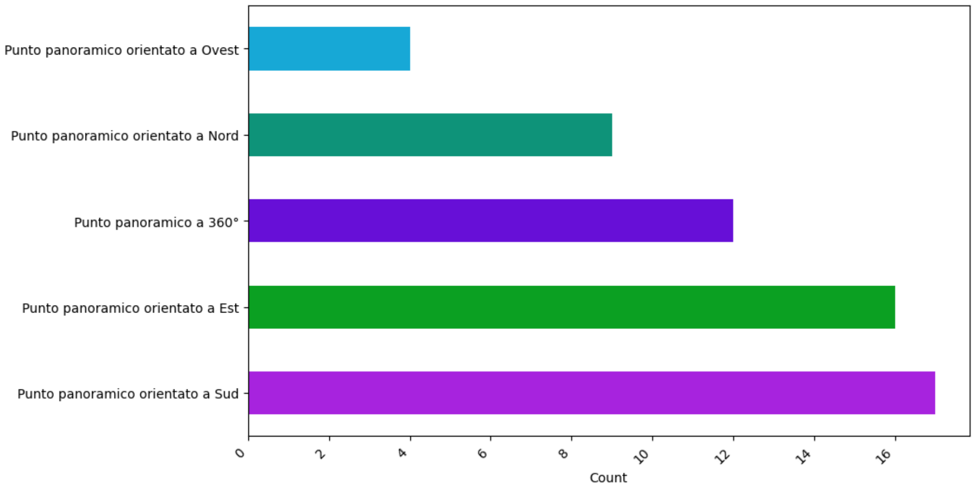

Fig. 12: Viewpoints orientation categories.

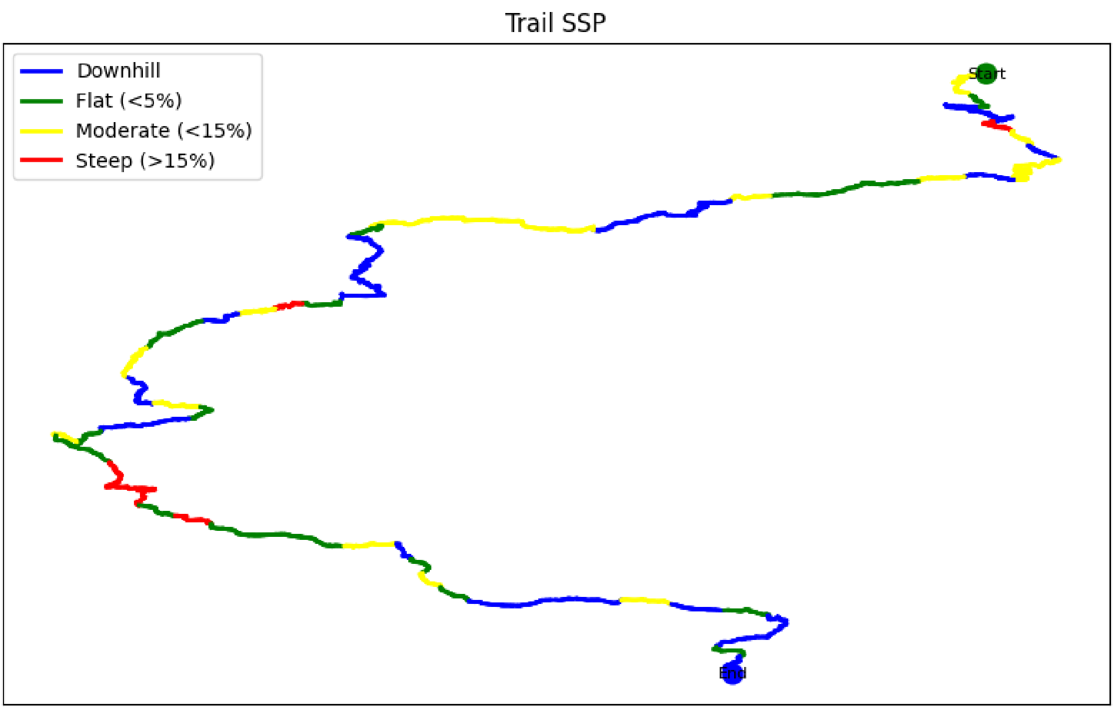

Fig. 13: Slope segments for trail SSP.

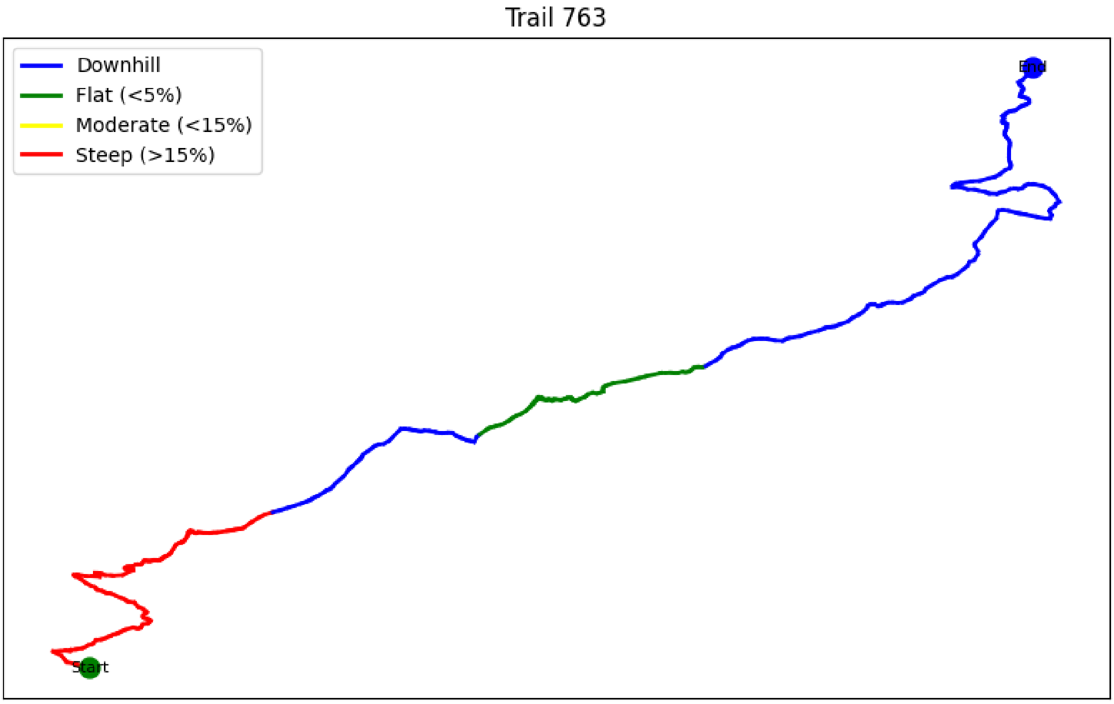

Fig. 14: Slope segments for trail 763.

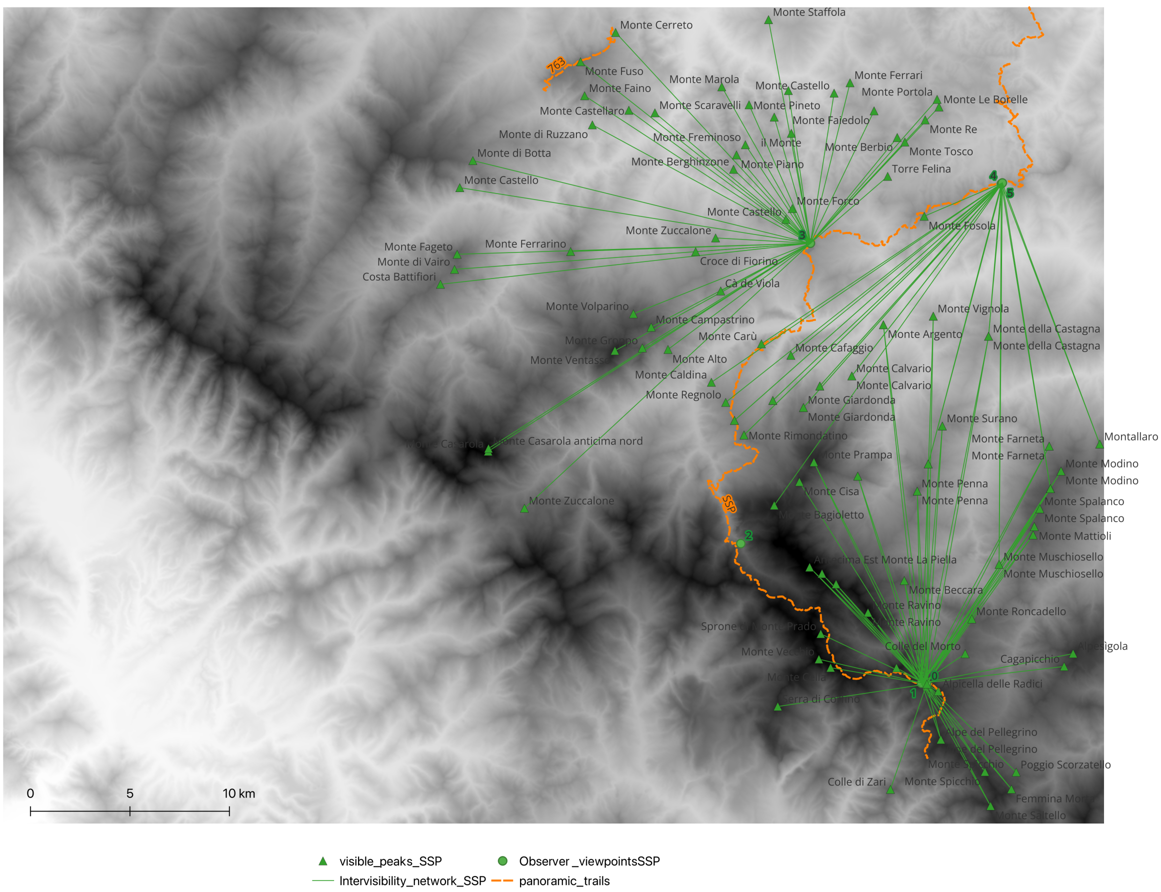

Fig. 15: Mountain peaks visible from trail SSP.

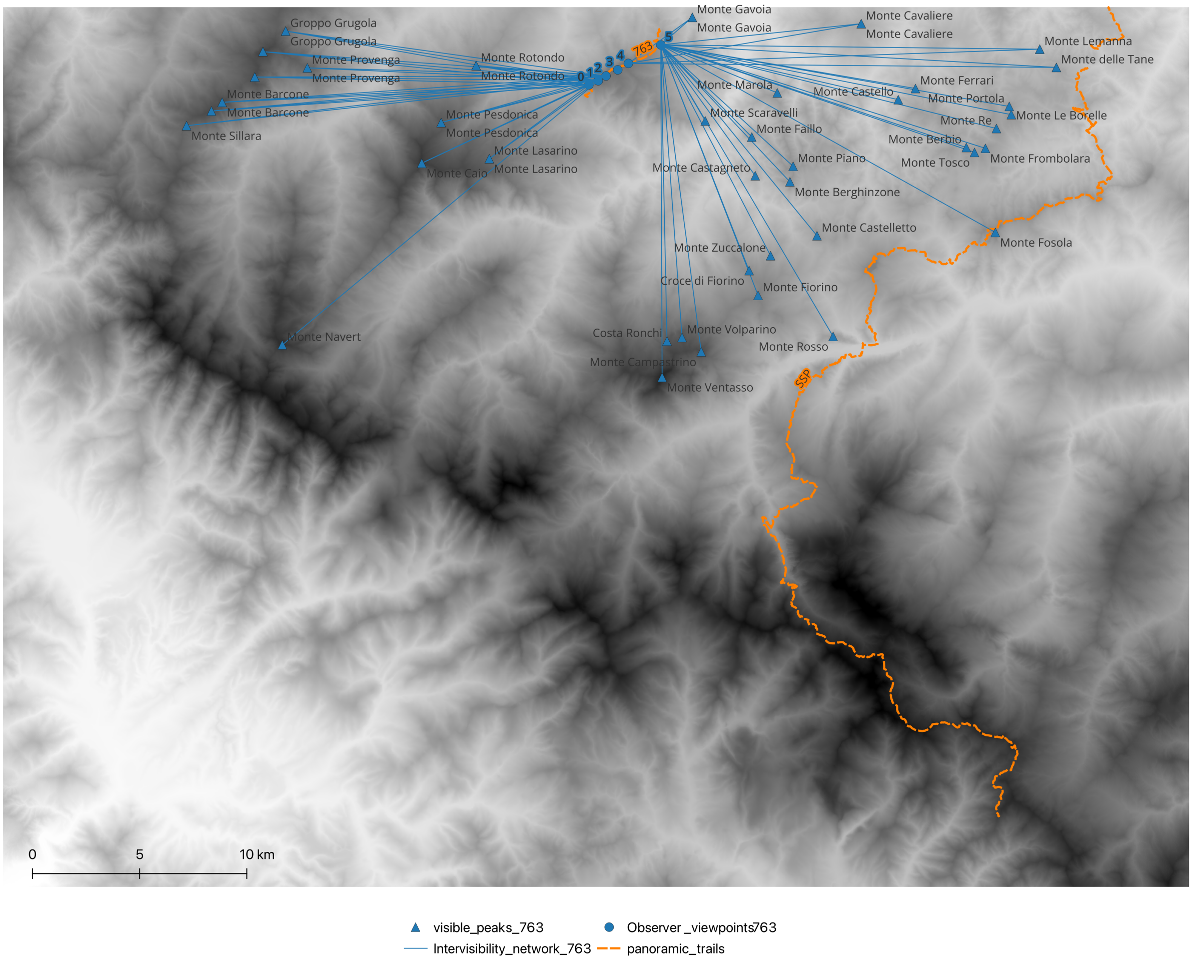

Fig. 16: Mountain peaks visible from trail 763.

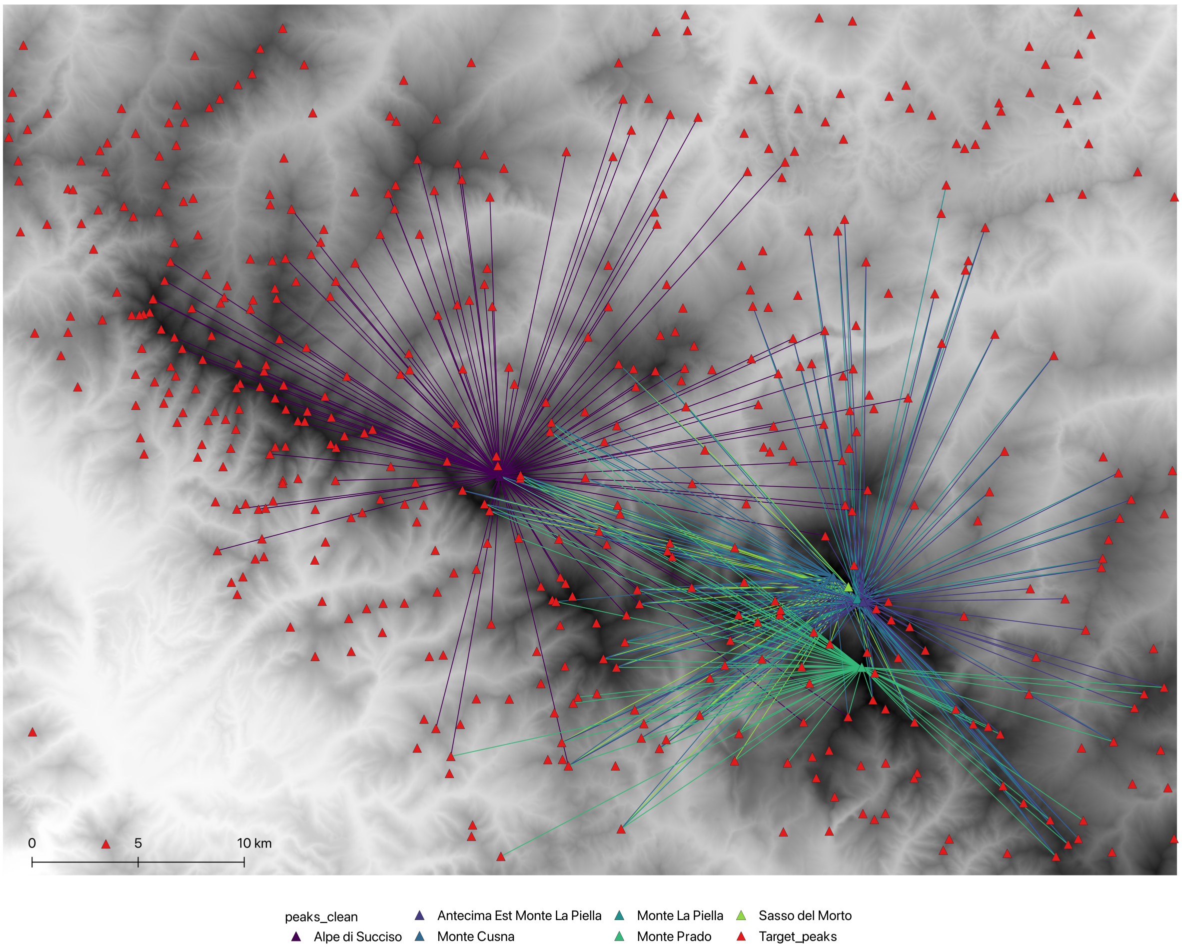

Fig. 17: Intervisibility network from peaks above 2000m.

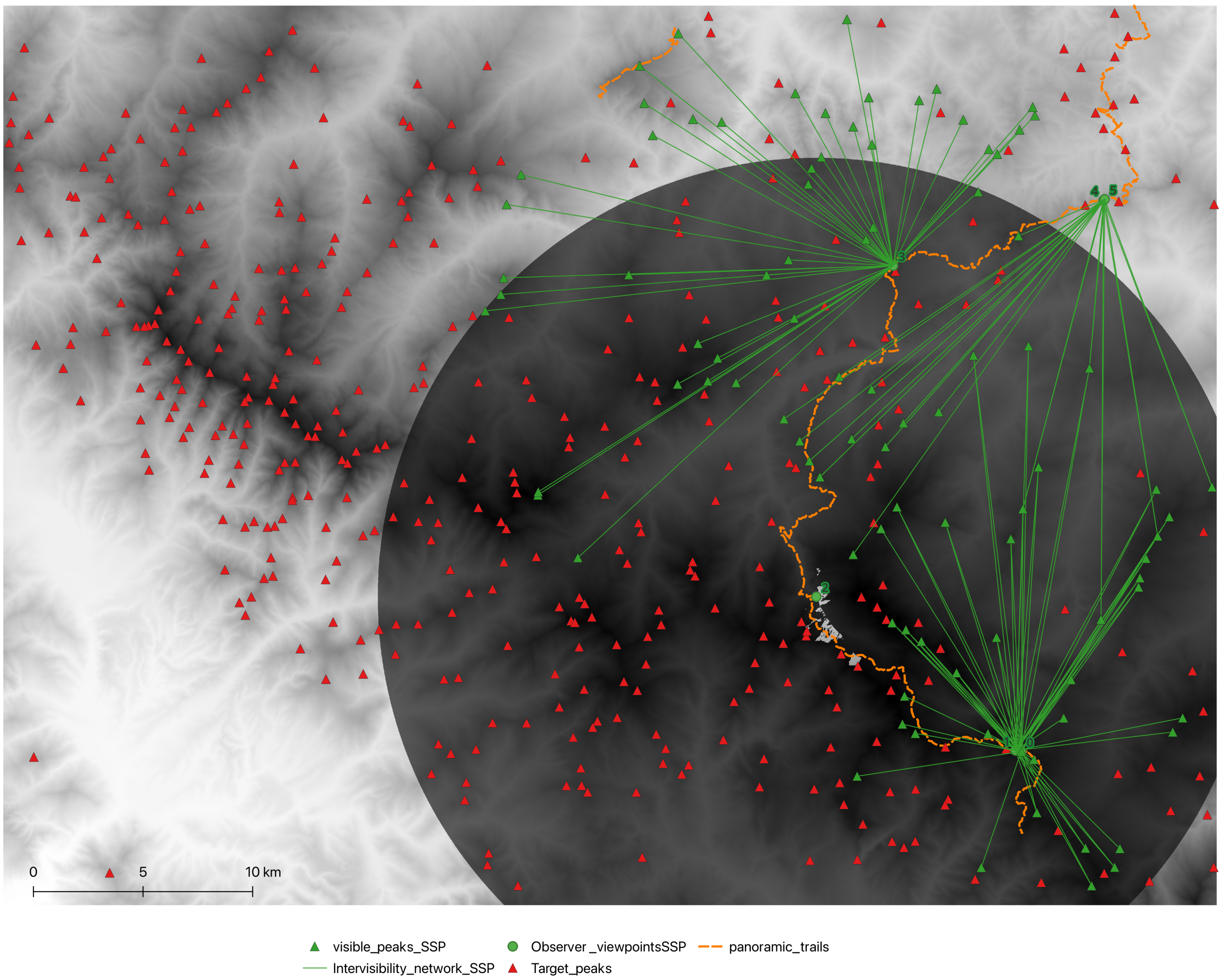

Fig. 18: Viewshed map for panoramic viewpoint 2 on SSP trail. The black portion of the radius indicates the area is not visible. The white portions represent the visible areas.

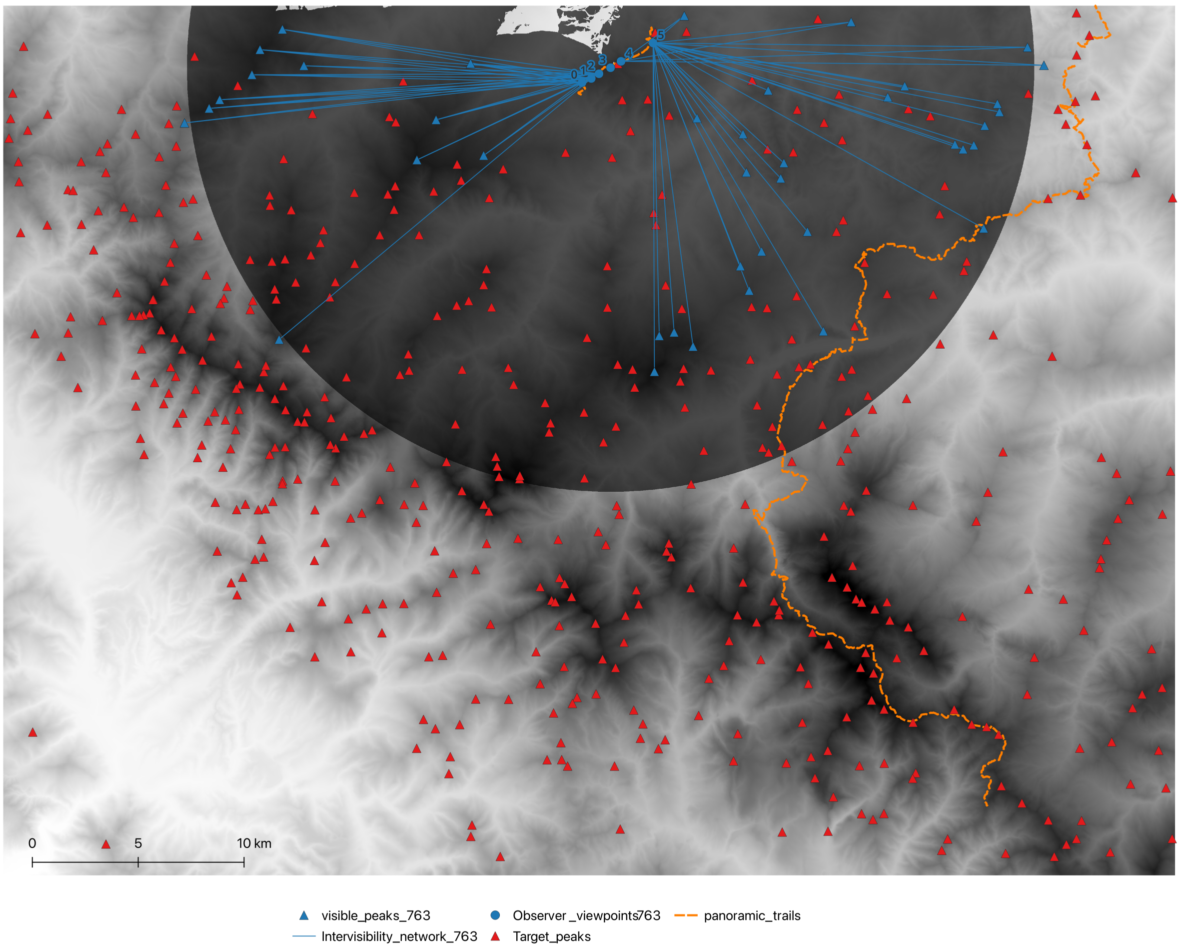

Fig. 19: Viewshed map for panoramic viewpoint 3 on 763 trail.